Objective 10

Light and Color
Relate EM radiation properties,
Describe how light is produce with E level diagrams,
Understand quantization.
Light and Color

Structure of Atom

Electrons

Valence Electrons

Bonding

Molecular Structure

Properties:
- Polarity
- Solubility
- b.p. and m.p.
- States of Matter
- IM forces

Shape
Light is Electromagnetic (EM) Radiation
EM radiation has Electric and Magnetic Field components
Transmission of energy by **waves**
Animation: [http://dwb4.unl.edu/ChemAnime/atomic_orbits.htm](http://dwb4.unl.edu/ChemAnime/atomic_orbits.htm)

EM Radiation travels at **speed of light** \( (c = 3.00 \times 10^8 \text{ m/sec}) \)

\[
\text{Energy} = \text{E (in J)} = h\nu = \frac{hc}{\lambda}
\]

where \( h = \text{Planck’s constant} = 6.63\times10^{-34} \text{ J sec} \)
\( \nu = \text{frequency} = \frac{c}{\lambda} \)
\( \lambda = \text{wavelength} \)
**Objective**: relate wavelength to frequency to energy

**Light is a Wave** - quantified by **wavelength**, **frequency**, **speed**, and **amplitude**.

Which wave has the longer wavelength?
Which wave has the higher frequency?
Which wave has the higher energy?

More wave properties: Reflection, Refraction, Diffraction
A supermarket scanner uses a He-Ne laser, which emits 656 nm red light.

Objective: Calculate the energy in J of 656 nm red light.

a. $6.56 \times 10^7$

b. $4.57 \times 10^{14}$

c. $3.03 \times 10^{-19}$
Color is Light We Can See - Visible Light

Calculate the energy in J of 656 nm red light.

\[
E \ (\text{in J}) = h\nu = \frac{hc}{\lambda}
\]

\[
= (6.63 \times 10^{-34} \ \text{J sec})(3.00 \times 10^8 \ \text{m/sec})
\]

\[
= \frac{656 \times 10^{-9} \ \text{m}}{6.03 \times 10^{-19} \ \text{J}}
\]

\[
= 3.03 \times 10^{-19} \ \text{J}
\]

Visible light is one slice of the Electromagnetic Spectrum.

Where does light (EM radiation) come from?
Our Body is a Good Detector of EM Radiation

http://www.eslsmartboard.com/vocabulary_lessons/face_and_body/human_body/
EM Radiation Detectors: 

**Charge Coupled Device** (CCD) – UV, Vis, and IR photon hits doped Si and ejects electron (PE effect) \(\rightarrow\) electrical signal

http://www.specinst.com/What_Is_A_CCD.html

Photomultiplier tube, film, CMOS
Photo-conductive cells, e.g., CdS
Photovoltaic cells, e.g., Se

X-rays – photographic film (Ag), semiconductors (Si (Li), CdTe)
Scientists, such as astronomers, like to talk about **redshifts** and **blueshifts**. If the universe is *expanding*, as astronomers believe, would you observe a redshift and blueshift?

The Radiation Type Has a Different Effect on Matter

**Microwaves** Cause Molecules to **Rotate** (spin)

**IR** Causes Bonds to **Vibrate**

**Visible** and **UV** Causes Bonds to **Break**!

Water boils when placed in a microwave oven but will ice melt in a microwave?

**Objective**: Describe How Light Is Produced

When a ____ absorbs the right amount of E, an _____ undergoes a transition from a _____ energy state to a _____ energy state (excited state).

*Light is Produced* when an _____ undergoes a transition from a _____ energy state to a _____ energy state.

What does “energy of an electron is quantized” mean?
What is a Quantum?
What is Quantized?

Egg

Baseball

Ramp

Stairs
Lab 8: How is light produced in a Ne gas discharge tube?

http://www.m2c3.com/chemistry/VLI/M1_Topic2/M1_Topic2_print.html
Why do different substances emit different colors or wavelengths of light?

**Fireworks**

**Flame Tests**
[http://www.daviddarling.info/encyclopedia/F/flame_test.html](http://www.daviddarling.info/encyclopedia/F/flame_test.html)
Why do different substances emit different colors or wavelengths of light?

**Fireworks**

Which E level diagram, A or B, represents green?
Which E level diagram, A or B, represents red? Give reasons.
Lab 8. Color (and Light) Is Quantified By __________
The λ’s of Light Emitted by a Substance isMeasured in an Emission Spectrum
An Emission Spectrum is Used to Identify Substances (like a fingerprint)

Astronomers use emission spectra to identify a star’s composition.

Emission spectrum of sun

H emission spectrum
http://coolcosmos.ipac.caltech.edu/cosmic_classroom/ir_tutorial/spec.html

A spectrometer is used to measure an emission spectrum. How does a spectrometer work?
The emission spectrum tells us the composition of this star.

What is the composition of this star?
Objective: relate emission spectrum to electronic structure

An Emission Spectrum tells us about Electronic Structure (energy states of electrons in an atom or molecule)

Given an energy level diagram, draw an emission spectrum that fits the diagram.

Energy Level Diagram

Emission Spectrum
Objective: relate emission spectrum to electronic structure

You measured the emission spectrum of a new substance you have just synthesized. Determine the electronic structure of this substance. In other words, draw an energy level diagram that fits the emission spectrum.
An Emission Spectrum tells us about Electronic Structure
Solution:

Energy Level Diagram

Emission Spectrum
**Objective**: relate emission spectrum to electronic structure

You measured the emission spectrum of a new substance you have just synthesized. Determine the electronic structure of this substance. In other words, draw an energy level diagram that fits the emission spectrum. **See Practice Problem 3.**
The *Emission Spectrum* of the *H atom* is described by **Bohr’s Model**

Postulates:
1. Energy of an electron has specific, not arbitrary, values (energy of an electron is *quantized*)
   \[ E = -\frac{R_H}{n^2} \]
   where \( R_H \) = Rydberg’s constant = \( 2.18 \times 10^{-18} \) J
   and \( n = 1, 2, 3, \ldots \)

   **This Equation Can ONLY Be Used for the H atom!!**

2. Electrons can undergo transitions from one energy state to another:
   - Lower E state --> Higher E state absorption
   - Higher E state --> Lower E state emission
   (2 others)

What is E of the n = 1 electron energy state in H?  
What wavelength is emitted in the n = 2 to n = 1 transition?
Hydrogen Emission Spectrum

http://coolcosmos.ipac.caltech.edu/cosmic_classroom/ir_tutorial/spec.html

Lab 8. Identify the electron states that produces each color.

<table>
<thead>
<tr>
<th>E, $x10^{-18}$ J</th>
<th>n = 4</th>
<th>n = 3</th>
<th>n = 2</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>-1</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>-2</td>
<td></td>
<td></td>
<td></td>
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<tr>
<td>n = 1</td>
<td></td>
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</tbody>
</table>

<table>
<thead>
<tr>
<th>Observed Wavelength, nm</th>
<th>Observed Color</th>
<th>$\frac{1}{\lambda R}$</th>
<th>$n_i$</th>
<th>$n_f$</th>
<th>$(\frac{1}{n_f^2} - \frac{1}{n_i^2})$</th>
<th>$\Delta E, J$</th>
</tr>
</thead>
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</tbody>
</table>
E, J

http://www.files.chem.vt.edu/RVGS/ACT/notes/notes-electronic_structure.html

E = -R_H/9
E = -R_H/4
E = -R_H
Light is Used In Many Different Ways and Applications

Fluorescent lights [http://home.howstuffworks.com/fluorescent-lamp.htm](http://home.howstuffworks.com/fluorescent-lamp.htm)

Lasers
Supermarket scanners - He/Ne laser

TV [http://electronics.howstuffworks.com/tv.htm](http://electronics.howstuffworks.com/tv.htm)
Electron gun inside TV [http://electronics.howstuffworks.com/question694.htm](http://electronics.howstuffworks.com/question694.htm)

LCD [http://electronics.howstuffworks.com/lcd2.htm](http://electronics.howstuffworks.com/lcd2.htm)

LED – see 2014 Nobel Prize in Physics

Reactant in Chemical Reactions - Photochemistry
Cameras - analog and digital

Information transfer (radio, cell phones, fiber optics)
How Fluorescent Lamps Work
(http://home.howstuffworks.com/fluorescent-lamp1.htm)

Hg (l) --> Hg (g)
Hg emits UV.
UV excites phosphor.
Phosphor emits white light.

What excites Hg?

Why do different substances emit different colors or wavelengths of light?
Mercury (Hg) Is Used In Fluorescent Lights which is the reason fluorescent lights should not be thrown out with the garbage.

The 546.1 nm line is used to calibrate light detectors and diffraction gratings.

Calculate the frequency and energy in J/photon and kJ/mole.

What Is A Photon?
Light as a Reactant in a Chemical Reaction

Dentistry:
Blue light for curing composite resins

Light as a Product in a Chemical Reaction

Fireflies
Light sticks


http://science.howstuffworks.com/zoo/chemistry/question554.htm

http://onlyhdwallpapers.com/tag/lightsabers/
Supply Energy to Produce Light

Supply Light to Produce Energy
Lab 8: Glowing pickle??
What makes the pickle glow this color?

http://www.fotosearch.com/illustration/pickle.html

Lasers are used in supermarket scanners, medical and industrial uses.

Laser Properties:
1. Directionality (tight beam, strong and focused). Compare to flashlight.
2. High spectral brightness
3. Monochromaticity (spectral purity) – narrow bandwidths. Some lasers have bandwidths < 1 MHz (or $10^{-4}$ cm$^{-1}$)
4. Coherence (light waves of similar frequency and well defined phase relationships)
5. Short pulses – some lasers have pulse widths < $10^{-13}$ sec

3 Elements of a Laser:
1. Active medium
2. Energy pump source (to create population inversion)
3. Resonant cavity to contain light
The gemstone ruby is alumina ($\text{Al}_2\text{O}_3$) doped with Cr$^{3+}$. The color of a ruby is due to electron transitions of Cr$^{3+}$ in alumina. These electron transitions can be used in a ruby laser. Three transitions occur: one transition corresponds to a wavelength of 545 nm, another transition corresponds to a wavelength of 694 nm, and a third transition corresponds to a wavelength of 2550 nm. See Practice Problem 5. 

\[ \text{Level 3} \quad \text{Level 2} \quad \text{Level 1} \]

a. Rubies are red. Which transition gives ruby its color? Be specific with the initial and final energy levels. Give reasons.

b. In a laser,
   (i) a flash tube excites (pumps) electrons in Cr$^{3+}$ from Level 1 to Level 3. Which wavelength corresponds to this transition?
   (ii) Electrons from Level 3 undergo a transition to Level 2 to release heat and create a population inversion (high number of excited state electrons). Which wavelength corresponds to this transition?

Confirm that $\Delta E$ for the Level 1 to Level 3 transition equals the sum of $\Delta E$ for the Level 3 to Level 2 transition and $\Delta E$ for the Level 2 to Level 1 transition.
Solution: The color of a ruby is due to electron transitions of Cr$^{3+}$ in alumina. Three transitions occur:

<table>
<thead>
<tr>
<th>$\lambda$, nm</th>
<th>Color</th>
<th>$\Delta E$, J</th>
<th>$\Delta E$, kJ/mole</th>
<th>Transition</th>
</tr>
</thead>
<tbody>
<tr>
<td>545</td>
<td>green</td>
<td>$3.65 \times 10^{-19}$</td>
<td>219.7</td>
<td>1 --&gt; 3</td>
</tr>
<tr>
<td>694</td>
<td>red</td>
<td>$2.87 \times 10^{-19}$</td>
<td>172.5</td>
<td>2 --&gt; 1</td>
</tr>
<tr>
<td>2550</td>
<td>IR</td>
<td>$0.78 \times 10^{-19}$</td>
<td>47.0</td>
<td>3 --&gt; 2</td>
</tr>
</tbody>
</table>

$\Delta E_{1\rightarrow3} = \Delta E_{3\rightarrow2} + \Delta E_{2\rightarrow1}$

$3.65 \times 10^{-19}$ J = $0.78 \times 10^{-19}$ J + $2.87 \times 10^{-19}$ J
Transition Metals Give Gemstones Their Color

<table>
<thead>
<tr>
<th>Gemstone</th>
<th>Color</th>
<th>Formula</th>
</tr>
</thead>
<tbody>
<tr>
<td>Ruby</td>
<td>Red</td>
<td>$\text{Cr}^{3+}$ in $\text{Al}_2\text{O}_3$</td>
</tr>
<tr>
<td>Emerald</td>
<td>Green</td>
<td>$\text{Cr}^{3+}$ in beryllium aluminum silicate</td>
</tr>
<tr>
<td>Sapphire</td>
<td>Blue</td>
<td>$\text{Fe}^{3+}$ and $\text{Ti}^{4+}$ in $\text{Al}_2\text{O}_3$</td>
</tr>
<tr>
<td>Garnet</td>
<td>Red</td>
<td>$\text{Fe}^{2+}$ in $\text{Mg}_3\text{Al}_2(\text{SiO}_4)_3$</td>
</tr>
<tr>
<td>Peridot</td>
<td>Yellow-green</td>
<td>$\text{Fe}^{2+}$ in $\text{Mg}_2\text{SiO}_4$</td>
</tr>
<tr>
<td>Turquoise</td>
<td>Blue-green</td>
<td>$\text{Cu}^{2+}$ in $\text{CuAl}_6(\text{PO}_4)_4(\text{OH})_8 \cdot 4\text{H}_2\text{O}$</td>
</tr>
<tr>
<td>Diamond</td>
<td>Colorless, pale blue or yellow</td>
<td>$\text{N}$ atoms trapped in crystal</td>
</tr>
</tbody>
</table>

Spectroscopy Is The Interaction of Light With Matter

What happens when light comes in contact with a substance?

Light is **reflected** off of substance.
Light is **transmitted** through substance.
Light is **absorbed** by the substance.
Light is **absorbed** by the substance, then **emitted** by substance.
An **Emission** Spectrum Measures the $\lambda$ ‘s of Light **Emitted** by a Substance

An **Absorption** Spectrum Measures the $\lambda$ ‘s of Light **Absorbed** by a Substance

E Level Diagram
Shows the energy of electron energy states

### Emission Spectrum
$\lambda$ ‘s emitted is color you see

### Absorption Spectrum
$\lambda$ ‘s absorbed is **not** color you see ==>
complementary color is color you see

Color Wheel
**Objective**: relate absorbed color to observed (complementary) color

If a substance absorbs red, it appears _____.

If a substance appears blue, it absorbs ______.

http://trehautecouture.blogspot.com/2012/06/how-to-mix-colors-in-your-wardrobe.html

Chlorophyll is the **Green** pigment in plants. What color is absorbed by chlorophyll? See Practice Problem 6.

http://www.webexhibits.org/causesofcolor/7A.html
A Substance **Absorbs a** **Specific Wavelength of Light**  
The Amount of Light Absorbed by the Substance (chromophore) is Proportional to Concentration

**Beer’s law:** \( A \propto C \)  
where \( A = \) Absorbance  
and \( C = \) concentration

Which solution absorbs more light? What color is absorbed?  
Which solution is less concentrated?

Beer’s law is used to determine the concentration of a substance in a solution.  
E.g., breath analyzer
Sunglasses are designed:
  • to protect your eyes from glare (polarized)
  • UV light (DNA damage)
  • to make you look cool.

Some sunglasses claim “100% UV protection” but …
“Sunglasses Carry Shady UV-Protection Claims, Study Reveals”

**Lab 8:** How would you test sunglasses?

*Bring A Pair Of Sunglasses To Lab!*
Sun Protection Factor (SPF) tells you how much UV light is absorbed:

$$\text{SPF} = \frac{1}{T} = \frac{1}{1 - A}$$

where $T$ = transmittance (light of specific $\lambda$ transmitted through sample) and $A$ = Absorbance (light of specific $\lambda$ absorbed by sample)

<table>
<thead>
<tr>
<th>SPF</th>
<th>A</th>
</tr>
</thead>
<tbody>
<tr>
<td>15</td>
<td>0.933</td>
</tr>
<tr>
<td>20</td>
<td>0.95</td>
</tr>
<tr>
<td>30</td>
<td>0.967</td>
</tr>
<tr>
<td>50</td>
<td>0.98</td>
</tr>
</tbody>
</table>
Lab 8. Absorption Spectra applications

Measure the Absorption Spectra of 2 food colors.

Mix 2 food colors to get a new color. Measure the Absorption Spectrum. Did a chemical reaction occur?

Bring A Colored Food To Lab.
Extract the color from the food. Measure the Absorption Spectrum. Is the color from the food a food coloring?
Wint-O-Green Lifesavers: See Practice Problem 7.


Light and Color

Where does light come from?

How is light produced?

Why do different substances have different color?

How is light studied?

What does the study of light tell us?
TiO$_2$ is a White Pigment used in Paint and Food coloring

Nano-sized TiO$_2$ added to concrete keeps concrete white

http://cen.acs.org/articles/89/i24/Building-Small.html

Self-cleaning property:

\[
\text{TiO}_2 + \text{UV light} \rightarrow \text{excited TiO}_2^* 
\]

TiO$_2^*$ works as a catalyst for oxidizing organic grime and “eats” smog (NO$_x$, SO$_x$, carbon monoxide, aromatics, ammonia, and aldehydes)

Add TiO$_2$ to surfaces to reduce air pollution.
Application: Far IR is used in chemical analysis and 1 Terahertz (THz) = 10^{-12} Hz
Development of instrumentation for THz spectroscopy. Detects small amounts of C-4 explosives hidden in sealed envelopes (590 cm^{-1}). C-4 cannot be detected by X-rays or metal detectors.

Imaging in medical, security, and other applications that capitalize on the light's ability to penetrate plastics, paper, and textiles
Burning of Fossil Fuels ==> Global Warming

2007: World oil demand = 85 million barrels/day
US oil demand = 20 million barrels/day,
    approx 10 million barrels/day for gasoline,
    141 billion gallons gas/year
California = 16 billion gallons gas/year

Gasoline is a mixture of hydrocarbons.
One gallon of burned octane produces 8250 g of CO₂.

\[ \text{CO}_2 \text{ absorbs IR radiation ==> IR = heat} \]

The amount of IR radiation (heat) absorbed by CO₂ is proportional to the CO₂ concentration. (Beer’s law: \( A \propto C \))

\[ \text{Atmospheric } [\text{CO}_2] = 380 \text{ ppm} \]
References:
Greenhouse gases explained
http://tonto.eia.doe.gov/energyexplained/index.cfm?page=environment_about_ghg
CO₂ absorption spectrum
http://www.iitap.iastate.edu/gccourse/forcing/images/image7.gif
Solar radiation in and earth’s thermal radiation out
http://www.te-software.co.nz/blog/augie_auer.htm
Global warming potential table http://unfccc.int/ghg_data/items/3825.php
CO₂ and T data http://www.geocraft.com/WVFossils/temp_vs_CO2.html
CO₂ and T data last 800,000 years
Cold facts on global warming http://brneurosci.org/co2.html
Global warming: a chilling perspective
http://www.geocraft.com/WVFossils/ice_ages.html#anchor2117056
Iowa State global change course http://www.iitap.iastate.edu/gccourse/units01.html
Absorption Spectra of Atmospheric Gases and Solar/Earth Radiation

http://noconsensus.wordpress.com/2010/04/19/radiative-physics-yes-co2-does-create-warming/
More than a dozen independent temperature reconstructions affirm the conclusion that Earth’s temperature has risen sharply in the past century.
Atmospheric CO2 Concentrations (ppmv)
Last 200 Years
From Antarctica ice and air data

Temperature of Lower Atmosphere
Last 200 Years
From Satellite and S. Hemisphere ice and air data

http://www.geocraft.com/WVFossils/last_200_yrs.html
http://www.geocraft.com/WVFossils/last_400k_yrs.html
Carbon Cycle: Life on earth is carbon-based. Plants absorb CO$_2$ and emit oxygen as a waste product. Humans and animals breathe oxygen and emit CO$_2$ as a waste product.

All sources: Approx. 200 billion tons of carbon from CO$_2$ that enter earth's atmosphere each year (½ from oceans, ½ from volcanoes and decaying plants)

Human activity: 6 billion tons of carbon from CO$_2$.

CO$_2$ that goes into the atmosphere is recycled by terrestrial plant life and earth's oceans.

CO$_2$ concentration: 380 parts per million (ppm) = less than 4/100ths of 1% of all gases present. Compare to former geologic times.

Is CO$_2$ is an essential ingredient.
Is CO$_2$ is a nutrient or a pollutant?
Is plant growth stimulated by more CO$_2$?

http://www.geocraft.com/WVFossils/ice_ages.html
Australian sheep and cattle to be vaccinated to reduce CH\textsubscript{4} emissions.

Sheep and cattle in Australia produce 14% of Australia’s total greenhouse emissions (measured in CO\textsubscript{2} equivalents).

Vaccine will reduce CH\textsubscript{4} emissions by 20% in these animals (approx. 300,000 metric tons of CO\textsubscript{2}).

CH\textsubscript{4} ≈ 21 x more potent than CO\textsubscript{2} as a greenhouse gas.
(Chemical and Engineering News, 6/18/01, p. 104)

http://spudcomics.com/tag/farting-sheep/
1.3 billion cows in the world (2011)

U.S. Livestock produces 139.8 units of TgCO$_2$ equivalent (teragram carbon dioxide equivalent) 
$\approx$ 20\% of all human methane production and second only to natural gas systems
U.S. produces 5,637.9 units of TgCO$_2$ equivalent per year by burning fossil fuels

http://bigkingken.wordpress.com/2011/07/05/finally-a-post-on-cow-farts/
Toyota: Prius exhaust less harmful than sheep emissions

Question: Does one sheep emit more global warming CH₄ than one Prius emit global warming CO₂?
Seen in SF

http://www.freerepublic.com/focus/f-news/1864014/posts

Search for greenhouse gas emitters by facility, type of factory, amount and type of greenhouse gas, facility location, plant name

http://ghgdata.epa.gov/ghgp/main.do
Hot Times Ahead For Refrigerants
As worry over refrigerants' threat to the ozone layer recedes, concern over global warming rise.

Energy for refrigeration = 1/6 of global energy usage