Objective 10: Light and color: relate EM radiation properties (wavelength, frequency, energy). Describe how light is produced with energy level diagrams. Understand quantization.

**Quiz Practice problems:**

**Key ideas**:

For electromagnetic radiation, $E = h\nu = hc/\lambda$. Units: E in J, $\nu$ in 1/sec = Hz, h = Planck's constant = 6.63E-34 J sec, c = speed of light = 3.00E8 m/sec, $\lambda$ in m.

Electromagnetic (EM) radiation is produced in a 2 step process:

1. an electron in a substance absorbs enough energy to undergo a transition from a lower electron energy state to higher electron energy state. This higher electron energy state is called an excited state.
2. An electron in a higher electron energy state undergoes a transition to a lower electron energy state and releases energy in the form of light (EM radiation).

Electron energy states are quantized.

**Skills**:

Convert energy to wavelength to frequency.

Relate energy, wavelength, and frequency to specific region of electromagnetic spectrum or color of visible light.

Describe how light is produced from different sources, e.g., gas discharge tube, fluorescent light, with an energy level diagram.

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

Use Bohr model of H atom to explain H emission spectrum.

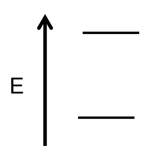
Distinguish between an emission spectrum and absorption spectrum.

Identify complementary colors.

Relate absorption spectrum to color of a substance.

1. A He-Ne laser emits 632.8 nm red light. This is the light source in supermarket scanners and in laser pen pointers. The Ne is responsible for the red color.

a. Use a simple energy level diagram to describe how red light is produced in this laser. Show the energy difference in Joules between the energy levels.




b. In a laser pointer, what is used as an excitation source?

c. Calculate frequency. Use $\nu = c/\lambda$ = (3.00E8 m/sec)/(632.8E-9 m) =

d. E of one photon. Use $E = h\nu$ or $E = hc/\lambda$. Units = J/photon

e. E of 1 mole of photons. Use Avogadro's number = 6.02E23 photons/mole.

f. If the electron energy states in a He/Ne laser were not quantized, what color of light would be emitted?

2. a. In the table below, estimate a wavelength for each type of electromagnetic (EM) radiation. Include units. Fill in the blanks.

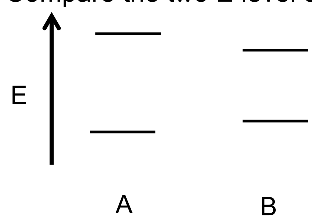
| Type of EM radiation | Wavelength, $\lambda$ | Frequency, $\upsilon$ | Energy of one photon, J | Energy of one mole of photons, kJ/mole |
|---|---|---|---|---|
| Radio waves | | | | |
| Microwaves | | | | |
| Infrared | | | | |
| Red light | | | | |
| Blue light | | | | |
| Ultraviolet | | | | |
| x-rays | | | | |

b. Name the human body part that detects each type of radiation. What is the physiological effect of exposure to each type of radiation?

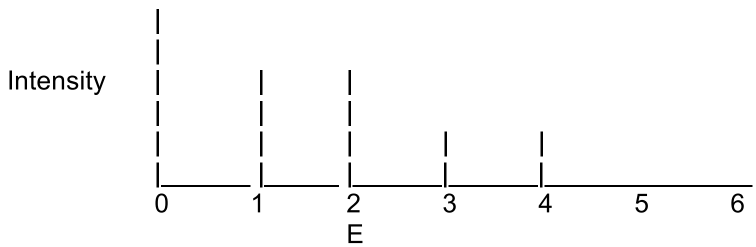
c. Extensive cell phone usage may have possible health effects according to some scientists. What type of electromagnetic radiation are emitted from cell phones? What is the effect of this type of radiation on the human body?

d. The following is an explanation of the heating process in microwave ovens: "Normal heating of food occurs when heat goes from the outside to the inside. Microwaves work just the opposite. The waves go to the inside and then move outward. The food molecules are hit by the electromagnetic radiation and forced to reverse polarity up to 100 million times a second. That is, the molecules start spinning. This tears them apart and sometimes rearranges them into toxic substances that cause many allergic responses. It is this friction which produces the heat which 'cooks' the food.

Unfortunately, this violent force also rips apart and deforms the molecular structure of the food. It is no longer ‘food’ – it just looks as though it is.”
Determine the validity of each sentence in this explanation.
e. Ionic salts are added to fireworks to give different colors. Copper salts, e.g., $CuCl_2$, produce a green color. Lithium salts, e.g., LiCl, produce a red color. Why do different elements produce different colors?
Compare the two E level diagrams. Which diagram, A or B, represents $CuCl_2$? Which diagram, B or A, represents LiCl?




3. You measured the emission spectrum of a new substance you have just synthesized.
a. Determine the electronic structure of this substance. In other words, draw an energy level diagram that fits the emission spectrum.




b. How would the absorption spectrum of this substance look like? Sketch this spectrum; plot Absorbance on the y axis and Energy on the x axis.

4. H emission spectrum and Bohr model.
In his model of a hydrogen atom, Bohr postulated that:
(i) the energy of an electron in a H atom is quantized, i.e., an electron can only have specific energy values called energy levels
(ii) a H atom radiates or absorbs energy only when the electron makes a transition from one energy level to another,
(iii) in each allowed energy state, an electron moves around the nucleus in a circular orbit of fixed radius,
(iv) in each allowed energy state, the angular momentum of the electron is quantized.
Compare Bohr's model of a hydrogen atom to the earth and the moon and answer the following questions.
a. Consider Postulate (i). How is this postulate similar to the earth and moon? How is this postulate not similar to the earth and moon?
b. Consider Postulate (ii). How is this postulate similar to the earth and moon? How is this postulate not similar to the earth and moon?
c. Consider Postulate (iii). How is this postulate similar to the earth and moon? How is this postulate not similar to the earth and moon?
d. Consider Postulate (iv). How is this postulate similar to the earth and moon? How is this postulate not similar to the earth and moon?
e. Is the earth-moon system a good model of a H atom? Explain.
f. According to current atomic theory, which of Bohr's postulates is/are incorrect? Give reasons.
g. The H emission spectrum shows lines. The absorption spectrum of red food coloring shows a peak instead of a line. Give one reason for this observation. Since a peak is observed instead of a line, does the quantization concept hold? Give reasons.

5. The gemstone ruby is alumina ($Al_2O_3$) 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:

i. when $Cr^{3+}$ absorbs 545 nm light from a flash tube, an electron undergoes a transition from Level 1 to Level 3,
ii. an electron undergoes a transition from Level 3 to Level 2 and corresponds to a wavelength of 2550 nm,
iii. an electron undergoes a transition from Level 2 to Level 1 and emits 694 nm light.

_____________ Level 3

___________ Level 2

______________________ Level 1

a. A ruby laser (alumina doped with $Cr^{3+}$) emits light of energy 172.5 kJ/mole (1000 J = 1 kJ). Which transition corresponds to this energy? Be specific with the initial and final energy levels. (Which equation relates E to wavelength?)
b. Rubies are red. Which transition gives ruby its color? Be specific with the initial and final energy levels. Give reasons.
c. 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.
d. Name one property or one application of a laser.

6. Plants use the green pigment chlorophyll to harvest light energy and convert it into chemical energy in the photosynthesis reaction:

$CO_2$ (g) + $H_2O$ (g) → $C_6H_{12}O_6$ (s) + $O_2$ (g).

a. Draw the absorption spectrum of chlorophyll. Plot wavelength in nm on the x-axis and absorbance on the y axis. State the approximate wavelength of light absorbed by chlorophyll. Then, draw a simple energy level diagram that represents the electron energy states in chlorophyll. Calculate the $\Delta E$ in J between the two energy levels.
b. What color would be <u>emitted</u> by chlorophyll? Give reasons. Would the emission spectrum of chlorophyll look the same or different than the absorption spectrum? Give reasons.
c. Is the photosynthesis reaction an oxidation-reduction reaction? If so, identify the oxidizing agent and reducing agent.
d. $CO_2$ and water are global warming or greenhouse gases because they absorb IR radiation. Can more trees reduce global warming of the earth's atmosphere? Give reasons.

7. Methyl salicylate($C_8H_8O_3$) is the wintergreen flavor in Wint-o-green Lifesavers. When Wint-o-green Lifesavers are crushed with a tool (such as your teeth), they emit a blue spark. This phenomena is referred to as triboluminescence. When the candy is crushed, the crystalline structure is stressed and broken, sugar molecules are broken unequally, and an electrical potential difference is created across the pieces of candy. Electrons flow through the air space between two pieces of candy. Nitrogen molecules in the air absorb this electrical energy and undergo a transition to an excited state. The excited nitrogen molecules then emit ultraviolet light which is absorbed by the methyl salicylate molecules in the candy. The methyl salicylate molecules emit visible light in the form of blue-green sparks.
The triboluminescence of Wint-o-green Lifesavers occurs in 5 steps as represented by the following chemical reactions. The * represents an excited state.

sucrose + mechanical energy -----> broken sucrose + electrical energy (1)
$N_2$ (g) + electrical energy ----> $N_2$* (g) (2)
$N_2$* (g) -----> $N_2$ (g) + UV light (330 nm) (3)
$C_8H_8O_3$ + UV light (330 nm) ------> $C_8H_8O_3$* (4)
$C_8H_8O_3$* -----> $C_8H_8O_3$ + blue light (455 nm) (5).

a. Add the five equations together to get an overall equation. Would you expect the overall reaction to be exothermic or endothermic? Give reasons.
b. Which step(s) are emission processes? Give reasons.
c. Which step(s) are absorption processes? Give reasons.
d. Draw a simple energy level diagram for $N_2$. Calculate the energy difference ($\Delta E$) between the ground state and the excited state. Show this $\Delta E$ on your diagram. Calculate the minimum amount of electrical energy in Joules that is required for $N_2$ to undergo this transition. (Which equation relates wavelength to E?)
e. According to the above steps, 330 nm UV light excites methyl salicylate from its ground state to an excited state. 455 nm blue light is emitted when methyl salicylate de-excites (relaxes) back to its ground state. Draw a simple energy level diagram for methyl salicylate. Calculate the energy differences ($\Delta E$) between the ground state and the excited states and show these $\Delta E$ in your diagram.
f. Is the minimum amount of electrical energy that you calculated in part d sufficient for methyl salicylate to undergo a transition from its ground state to its excited state. Give reasons.
g. The triboluminescence of Wint-o-green Lifesavers could occur in a different sequence of steps. Provide a plausible explanation for steps (4) and (5) to occur before steps (2) and (3).
h. How many moles of photons of UV light are required to react with 100 mg of methyl salicylate? If $1\times10^{20}$ photons of UV light strikes 100 mg of methyl salicylate, will all of the methyl salicylate react? Give reasons.