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, ν in 1/sec = Hz, h = Planck's constant = 6.63E-34 J sec, c = speed of light = 3.00E8 m/sec, λ 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).

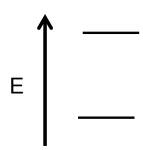
Electron energy states are quantized.

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) =

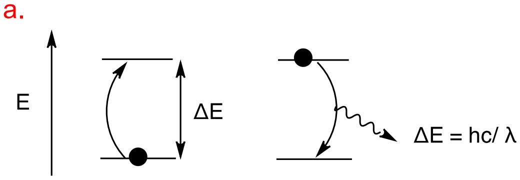
d. E of one photon. Use $E = h\nu$ or $E = hc/\lambda$. Units = J/photon

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?

Answers:

a.



absorption: "right" amount of energy absorbed (ΔE)

emission: energy released (emitted). Wavelength corresponds to ΔE.

Step 1: Ne absorbs energy equal to the difference between the two electron energy states (ΔE). An electron undergoes a transition from a lower energy state (the lowest energy state is called the ground state) to higher energy state. A higher energy state is called an excited state. This is called an absorption process. This process is endothermic.

For this transition, $\Delta E = hc/\lambda$ = (6.63E-34 J sec)(3.00E8 m/sec) / (632.8E-9 m) = 3.14E-19 J

Note: if Ne absorbs energy not equal to ΔE, an electron will not undergo a transition to a higher energy state. This is the idea of quantization.

Step 2: the electron in the higher electron energy state (excited state) electron undergoes a transition from the higher energy state to lower energy state. Energy is released (emitted) in the form of light. The wavelength of light emitted corresponds to $\Delta E = hc/\lambda$.

Rearrange this equation and solve for $\lambda = \Delta E / hc$ = (3.14E-19 J) / (6.63E-34 J sec)(3.00E8 m/sec) = 6.328E-7 m = 632.8 nm.

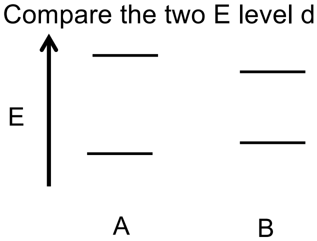
632.8 nm red light is emitted.

b. Laser pointer uses electricity from a battery as the excitation source.
c. ν = c/ λ = (3.00E8 m/sec)/(632.8E-9 m) = 4.74E14 Hz.
d. For one photon of 632.8 nm light, E = hc/ λ = (6.63E-34 J sec)(3.00E8 m/sec) / (632.8E-9 m) = 3.14E-19 J
e. For one mole of 632.8 nm light, E = 3.14E-19 J/photon (6.02E23 photons/mole) = 189000 J/mole = 189 kJ/mole
f. all colors = black. There would be different energy differences so each ΔE corresponds to a different wavelength.

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, λ	Frequency, υ	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?



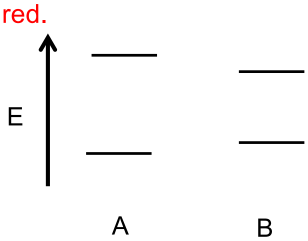
Answers:
a.

Type of EM radiation	Wavelength, λ in m	Frequency, υ in Hz	Energy of one photon, J	Energy of one mole of photons, kJ/mole
Radio waves	100	3E6	1.99E-27	1.2E-6
Microwaves	1.22 for microwave overn	2.45E9	1.62E-24	9.78E-4
Infrared	3.03E-6 to stretch an O-H bond	9.9E13	6.56E-20	39.5
Red light	6.5E-7	4.62E14	3.06E-19	184
Blue light	4.5E-7	6.67E14	4.42E-19	266
Ultraviolet	3E-7	1E15	6.63E-19	399
x-rays	1E-10	3E18	1.99E-15	1.2E6

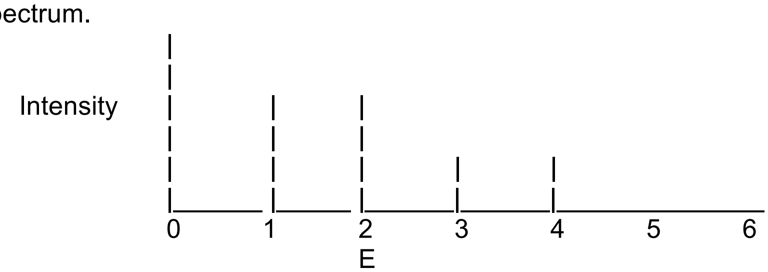
b. visible = eyes = color
radio = ears = sound
IR = skin = feels warm
UV = skin = sunburn
c. Cell phones emit radio frequencies in the 800 MHz band or 1800 MHz band. No conclusive scientific evidence links cell phone use with any adverse health problems (https://www.niehs.nih.gov/health/topics/agents/emf/index.cfm and https://www.who.int/peh-emf/about/WhatisEMF/en/index1.html and http://emfandhealth.com/).

d. microwave ovens: “Normal heating of food occurs when heat goes from the outside to the inside. True – in a conventional oven, the outside of food heats up first and warms the cooler inside of the food. In other words, heat is transferred from the hot air of the oven to the outside of the cold food. As the outer parts of the food increases in temperature, heat is transferred to the cooler inner parts of the food.
Microwaves work just the opposite. False – heating occurs where polar molecule, such as water and fat, are present in the food. Microwaves penetrate the food and excite the polar molecules uniformly, not from the inside to outside.
The waves go to the inside and then move outward. False – Microwaves penetrate the food and excite the polar molecules uniformly, not from the inside to outside.
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. Sort of true – Microwave radiation (2.4 to 2.5 GHz band) is absorbed by polar molecules in food. A polar molecule has a partial positive charge at one end and partial negative charge at the other end and rotate as they try to align themselves with the alternating electric field of the microwave electromagnetic radiation. In other words, the electric field exerts a force on the polar food molecules and causes them to rotate to align with the field.
Each wave of microwave radiation has a positive and negative component so the polar food molecules rotate at twice the rate of the microwave frequency, 2.45 GHz = 2.45E9 Hz = 2450 million cycles per second x 2 = 4.9 billion times a second = 4900 million times a second, not 100 million times a second.
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. False – the polar food molecules rotate and collide (bump) into other food molecules and transfers energy in the form of heat. This is called dielectric heating. friction is the rubbing of one body against another or the force resisting the relative motion of solid surfaces. Maybe the collisions between food molecules can be called friction.
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.” False – the food is still food. Heating up food can break chemical bonds depending on the temperature. For example, heating up a protein will break the hydrogen bonds that hold a protein in its secondary or tertiary structure and unfolds the protein and changes its shape. This is how meat is cooked.
References: https://en.wikipedia.org/wiki/Microwave_oven
https://home.howstuffworks.com/microwave2.htm
https://wtamu.edu/~cbaird/sq/2014/10/15/why-are-the-microwaves-in-a-microwave-oven-tuned-to-water/
http://tera.yonsei.ac.kr/class/2004_2/project/microwaveoven_team2.pdf

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. Different elements produce different colors because the energy difference, ΔE, between electron energy states is different. The energy difference produces different wavelengths and colors of light. $\Delta E = hc/\lambda$.
Compare the two E level diagrams. Diagram A represents $CuCl_2$.Which diagram B represents LiCl.
Green wavelengths are a higher energy than red wavelengths. ΔE for A is greater than ΔE for B so A is green and B is red.

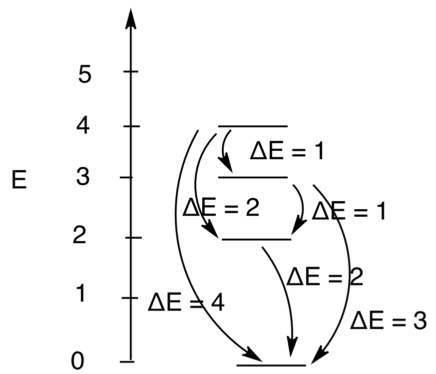


3. You measured the emission spectrum of a new substance you have just synthesized.
a. Determine the electronic structure of this substance. In other words, draw an energy level diagram that fits the emission spectrum.

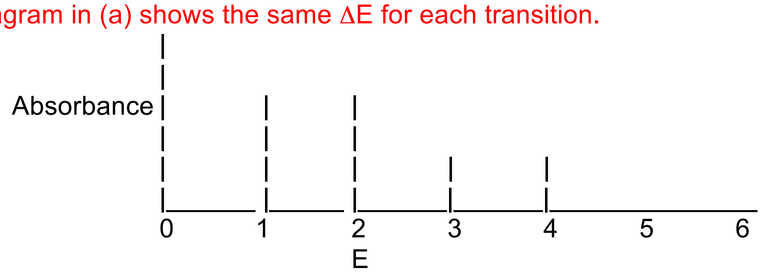


b. How would the absorption spectrum of this substance look like? Sketch this spectrum; plot Absorbance on the y axis and Energy on the x axis.
Answers:

a. Each peak (vertical line) represents an electron undergoing a transition from a hihger energy state to lower energy state – emission process.
The peak at E = 1 means an electron transition from a higher energy state to lower energy state has a ΔE = 1.
The peak at E = 2 means an electron transition from a higher energy state to lower energy state has a ΔE = 2.
The peaks at E = 1 and E = 2 are the same height.
The peak at E = 1 is twice as high as the peaks at E = 3 and E = 4. This means there are twice the number of transitions with ΔE = 1 as ΔE = 3 or ΔE = 4.
Here is a possible energy level diagram that fits the emission spectrum:
There are two transitions with ΔE = 1.
Two transtions with ΔE = 2.
One transition with ΔE = 3.
One transition with ΔE = 4.



b. The absorption spectrum looks the same as the emission spectrum – peaks at same E with same heights except Absorbance is plotted on the y axis instead of Intensity.
An absorbance spectrum shows electrons undergoing transitions from a lower energy to higher energy so the energy level diagram in (a) shows the same ΔE for each transition.



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.
Answers:

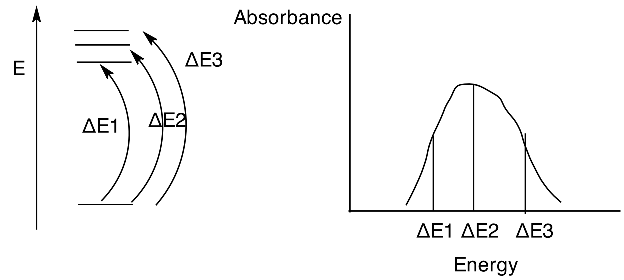
Postulates (i) and (ii) are based on the concept of quantization.
a. Postulate (i): the energy of an electron in the H atom is quantized.
Similar to earth and moon: the energy of the moon is quantized. The energy of the moon can be calculated in terms of kinetic energy = 0.5 mv^2 where m = mass and v = velocity. The mass of the moon is constant and the velocity of the moon as it revolves around the earth is constant (more or less), therefore the kinetic energy (KE) is constant. This one value for the KE is allowed; all other values are not allowed.
Not similar to earth and moon: the velocity of the moon as it revolves around the earth is not constant so the energy of the moon is not quantized.
b. Postulate (ii): an electron in a H atom can undergo transitions from one energy level to another.
Similar to earth and moon: the moon moves different distances between it and the earth. A certain amount of energy of required for a transition from one distance (energy state) to another to occur.
Not similar to earth and moon: if the energy of the moon is constant with only one value for the energy (see postulate (i) above), then the moon cannot and does not undergo transitions from one energy to another energy.

Postulates (iii) and (iv) are based on Newton's laws.
c. Postulate (iii): an electron moves around the nucleus in a circular orbit of fixed radius.
Similar to earth and moon: the moon orbits the earth in a circular orbit of fixed radius.
Not similar to earth and moon: the moon orbits the earth in an elliptical orbit rather than a circular orbit. The moon's orbit and the orbit of an electron according to Bohr's postulate can be described using Newton's laws. We now know that this postulate is not correct. The "orbit" of an electron is described in terms of quantum theory. An electron does not travel in any fixed orbit and is treated like a wave. The probability of finding an electron in a certain region of space is finite. The energy and position of an electron follows the uncertainty principle.
d. Postulate (iv): the angular momentum of an electron is quantized.
Momentum, which is defined by mass (m) times velocity (v), determines the length of time required to bring a moving body to rest when decelerated by a constant force. Linear momentum measures m times v along a straight line; angular momentum describes an analogous quantity for movement along a curved path.
Similar to earth and moon: the shape of the moon's orbit around the earth is fixed (elliptical) and can be considered to be quantized like the shape of atomic orbitals are quantized.
Not similar to earth and moon: since the moon's orbit is elliptical, the angular momentum of the moon changes depending on its position in orbit. Thus, the angular momentum of the moon is NOT quantized.

e. According to the possible answers that I have given, the earth-moon system is NOT a good model for the H atom. Although the moon's energy is quantized, the moon does not undergo transitions between energy levels, it does not move in a circular orbit of fixed radius, and its angular momentum is not quantized.
f. Postulate (iii) is entirely incorrect since it does not follow quantum theory; it violates the uncertainty principle.
Postulate (iv) is partially correct. The angular momentum of an electron is quantized. However, Bohr based the angular momentum of an electron on Newton's laws, angular momentum = mvr.
According to quantum theory, the allowed values of angular momentum of an electron in the H atom is given by:
$(l(l + 1))^{1/2}$ $(h/2\pi)$ where l is the angular momentum quantum number for a state with energy E_n, n = 1, 2, 3, ..., ∞.
The angular momentum quantum number (l) corresponds to postulate (iv). The l quantum number gives information about the shape of an atomic orbital.

l quantum number	Orbital
0	s
1	p
2	d
3	f

g. The H emission spectrum is produced from H gas. Gas molecules are far apart and we can assume the gas molecules do not interact with each other.
Red food coloring is a liquid. The food coloring molecules are closer together and chemical forces exist, e.g., intermolecular forces, between different food coloring molecules. These interactions change the electron energy states slightly so ΔE for each electron transition is slightly different. So several lines that are close to each other in energy look like a peak. The quantization concepts still holds.



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 ΔE for the Level 1 to Level 3 transition equals the sum of ΔE for the Level 3 to Level 2 transition and ΔE for the Level 2 to Level 1 transition.
d. Name one property or one application of a laser.

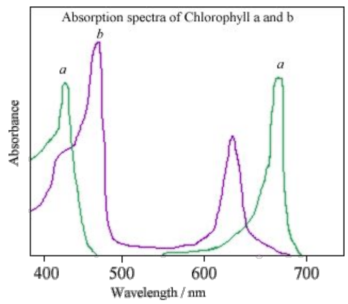
Answers:
a. Convert E from kJ/mole to wavelength: 172.5 kJ/mole (1000 J/1 kJ)(1 mole/6.02E23) = 2.87E-19 J
Rearrange ΔE = hc/ λ and solve for λ = (6.63E-34 J sec)(3.00E8 m/sec) / (2.87E-19 J) = 6.94E-7 m = 694 nm.
This wavelength indicates Transition iii: Level 2 to Level 1.
b. Transition iii: Level 2 to Level 1 produces 694 nm light ==> red.
c. Convert wavelength to energy using ΔE = hc/ λ.
Transition i: 545 nm ==> ΔE = (6.63E-34 J sec)(3.00E8 m/sec) / (545E-9 m) = 3.65E-19 J
Transition ii: 2550 nm ==> ΔE = (6.63E-34 J sec)(3.00E8 m/sec) / (2550E-9 m) = 0.78E-19 J
Transition iii: 2.87E-19 J
E of Transition i = E of Transition ii + E of Transition iii
3.65E-19 J = 0.78E-19 J + 2.87E-19 J
d. Laser properties: directionality (tight, focused beam compared to flashlight beam), high spectral brightness, monochromaticity, coherence, short pulses.
Laser applications: supermarket scanners (bar code scanners), spectroscopy, photochemistry, heat or cooling treatment, military weapons, guidance, cosmetic surgery, eye surgery, laser cutting, welding, drilling.

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

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

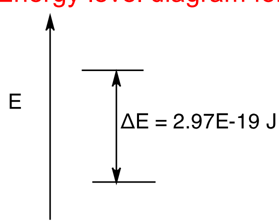
a. Draw the absorption spectrum of chlorophyll. Plot wavelength in nm on the x-axis and absorbance on the y axis. State the approximate wavelength of light absorbed by chlorophyll. Then, draw a simple energy level diagram that represents the electron energy states in chlorophyll. Calculate the ΔE in J between the two energy levels.
b. What color would be emitted 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.

Answers:
a.



http://www.webexhibits.org/causesofcolor/7A.html

Chlorophyll a is green. The absorption spectrum shows a peak at approximately 670 nm, which is a red wavelength.
ΔE = (6.63E-34 J sec)(3.00E8 m/sec) / (670E-9 m) = 2.97E-19 J
Energy level diagram for chlorophyll



b. Chorophyll would emit red light of wavelength = 670 nm. An electron undergoes a transition from a higher electron energy state to lower energy state with ΔE = 2.97E-19 J and emits 670 nm red light.
c. CO_2 (g) + H_2O (g) → $C_6H_{12}O_6$ (s) + O_2 (g).
Photosynthesis reaction is an oxidation-reduction reaction.
The oxidizing agent is CO_2 (the charge on C in CO_2 goes from +4 to 0 in $C_6H_{12}O_6$ so CO_2 is reduced) and reducing agent is water (the charge on O in H_2O goes from -2 to 0 in O_2 so H_2O is oxidized).
d. More trees can reduce global warming of the earth's atmosphere because the green leaves in trees can uptake CO_2 in photosynthesis and remove CO_2 from the atmosphere.

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 (ΔE) between the ground state and the excited state. Show this ΔE 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 (ΔE) between the ground state and the excited states and show these ΔE 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 1×10^{20} photons of UV light strikes 100 mg of methyl salicylate, will all of the methyl salicylate react? Give reasons.

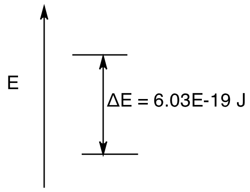
Answers:

a. overall equation: sucrose + mechanical energy -----> broken sucrose + blue light (455 nm)

b. Steps (1), (3), and (5) are emission processes. Energy is released in each step.

c. Steps (1), (2), and (4) are absorption processes. Energy is absorbed in each step.

d. N_2* emits 330 nm light in Step (3). So ΔE = (6.63E-34 J sec)(3.00E8 m/sec) / (330E-9 m) = 6.03E-19 J



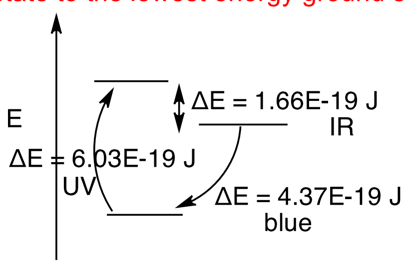
The minimum amount of electrical energy in Joules that is required for N_2 to undergo this transition in Step 2 is 6.03E-19 J.

e. 455 nm blue light has an ΔE = (6.63E-34 J sec)(3.00E8 m/sec) / (455E-9 m) = 4.37E-19 J

Step 1: methyl salicylate absorbs 303 nm UV light (ΔE = 6.03E-19 J) to form excited state methyl salicylate.

Step 2: an electron from excited state methyl salicylate undergoes a transition from the highest energy state to an lower energy excited state (ΔE = 1.66E-19 J) and releases energy in the form of heat. This is called an “intersystem transfer”.

Step 3: an electron from the lower energy excited state methyl salicylate undergoes a transition from this higher energy state to the lowest energy ground state (ΔE = 4.37E-19 J) and emits 455 nm blue light.



f. The minimum amount of electrical energy that you calculated in part d (6.03E-19 J) is sufficient for methyl salicylate to undergo a transition from its ground state to its excited state (6.03E-19 J). These energies match the energy difference between energy states.

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).

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

The electrical energy released in Step (1) is 6.03E-19 J (same energy as 330 nm UV light), then this sequence of steps could occur.

h. How many moles of photons of UV light are required to react with 100 mg of methyl salicylate? If $1x10^{20}$ photons of UV light strikes 100 mg of methyl salicylate, will all of the methyl salicylate react? Give reasons.

Convert mg methyl salicylate --> g methyl salicylate --> moles methyl salicylate --> moles UV light.

100 mg $C_8H_8O_3$ (1 g/1000 mg)(1 mole $C_8H_8O_3$ / 152 g $C_8H_8O_3$)(1 mole UV light/1 mole $C_8H_8O_3$) = 6.58E-4 moles UV

$1x10^{20}$ photons of UV (1 mole/6.02E23 photons) = 1.66E-4 moles

If $1x10^{20}$ photons (1.66E-4 moles) of UV light strikes 100 mg of methyl salicylate (6.58E-4 moles), not all of the methyl salicylate reacts ==> $1x10^{20}$ photons (1.66E-4 moles) of UV light is the limiting reactant.