Name: ______________________________ Date: ______________

Wavelength –

Frequency –

Speed of light –

Electromagnetic radiation –

Electromagnetic spectrum –

Planck's constant –

Quanta –

Photon –

Ground state –

Excited state –

Valence electrons –

Work function –

Heisenberg Uncertainty Principle –

Pauli Exclusion Principle –

Hund's Rule –

Aufbau principle –

Albert Einstein and the photoelectric effect –

Max Planck –

Erwin Schrödinger –

Wolfgang Pauli –

Werner Heisenberg –

Louis de Broglie –

EMR	Frequencies (Hz)		Frequencies		Wavelength (m)		Wavelengths	
Military communication	3.00E+03	3.00E+04	3 kHz	30 kHz	9993.33	99933.33	approx. 10 km	approx. 100 km
Navigation/Time	3.00E+04	3.00E+05	30 kHz	300 kHz	999.33	9993.33	approx. 1 km	approx. 10 km
AM radio (long wave - Europe)	1.53E+05	2.79E+05	153 kHz	279 kHz	1074.55	1959.48	1.07455 km	1.95948 km
AM radio (medium wave - North America)	5.35E+05	1.70E+06	535 kHz	1700 kHz	176.35	560.37		
AM radio (short wave - international)	5.90E+06	2.61E+07	5900 kHz	26.1 MHz	11.49	50.81		
Citizens band radio	2.696E+07	2.741E+07	26.96 MHz	27.41 MHz	10.94	11.12		
Garage door openers	4.000E+07		40 MHz		7.50			
Cordless phones	4.000E+07	5.000E+07	40 MHz	50 MHz	6.00	7.50		
Baby monitors	4.900E+07		49 MHz		6.12			
Television (network) stations 2 through 6	5.40E+07	8.80E+07	54 MHz	88 MHz	3.41	5.55		
Radio controlled airplanes	7.200E+07		72 MHz		4.16			
Radio controlled cars	7.500E+07		75 MHz		4.00			
FM radio	8.80E+07	1.08E+08	88 MHz	108 MHz	2.78	3.41		
Television (network) stations 7 through 13	1.74E+08	2.20E+08	174 MHz	220 MHz	1.36	1.72		
Wildlife tracking collars	2.150E+08	2.200E+08	215 MHz	220 MHz	1.36	1.39		
Cell phones	8.240E+08	8.490E+08	824 MHz	849 MHz	0.353	0.364	35.3 cm	36.4 cm
Air traffic control	9.600E+08	1.215E+09	960 MHz	1215 MHz	0.247	0.312	24.7 cm	31.2 cm
GPS (Global Positioning System)	1.227E+09		1227 MHz		0.24		24 cm	

EMR	Frequencies (Hz)		Frequencies		Wavelength (m)		Wavelengths	
GPS (Global Positioning System)	1.58E+09		1575 MHz		0.19		19 cm	
Deep space radio communication	2.290E+09	2.300E+09	2290 MHz	2300 MHz	0.1303	0.1309	13.03 cm	13.09 cm
Microwaves - microwave oven	2.450E+09		2.45 GHz		0.12		12 cm	
Microwaves - ultra-high frequency (UHF)	3.000E+08	3.000E+09	.3 GHz	3 GHz	0.0999	0.9993	9.99 cm	99.93 cm
Microwaves - super high frequency (SHF)	3.000E+09	3.000E+10	3 GHz	30 GHz	0.0100	0.0999	1.00 cm	9.99 cm
Microwaves - extremely high frequency (EHF)	3.000E+10	3.000E+11	30 GHz	300 GHz	0.0010	0.0100	1.0 mm	1.00 cm
Far infrared (FIR)	3.00E+11	2.00E+13	300 GHz	20 THz	1.5E-05	1.0E-03	15 µm	1000 µm
Long wavelength infrared (LWIR)	2.00E+13	3.75E+13	20 THz	37.5 THz	8.0E-06	1.5E-05	8 µm	15 µm
Mid wavelength infrared (MWIR)	3.75E+13	9.99E+13	37.5 THz	99.9 THz	3.0E-06	8.0E-06	3 µm	8 µm
Short wavelength infrared (SWIR)	9.99E+13	2.14E+14	99.9 THz	214 THz	1.4E-06	3.0E-06	1.4 µm	3 µm
Near infrared (NIR)	2.14E+14	4.28E+14	214 THz	428 THz	7.0E-07	1.4E-06	0.7 µm	1.4 µm
Red	4.05E+14	4.80E+14	405 THz	480 THz	6.25E-07	7.40E-07	625 nm/6250 Å	740 nm/7400 Å
Orange	4.80E+14	5.08E+14	480 THz	508 THz	5.90E-07	6.25E-07	590 nm/5900 Å	625 nm/6250 Å
Yellow	5.08E+14	5.31E+14	508 THz	531 THz	5.65E-07	5.90E-07	565 nm/5650 Å	590 nm/5900 Å
Green	5.31E+14	5.77E+14	526 THz	577 THz	5.20E-07	5.65E-07	520 nm/5200 Å	565 nm/5650 Å
Cyan	5.77E+14	6.00E+14	577 THz	600 THz	5.00E-07	5.20E-07	500 nm/5000 Å	520 nm/5200 Å

EMR	Frequencies (Hz)		Frequencies		Wavelength (m)		Wavelengths	
Blue	6.00E+14	6.81E+14	600 THz	681 THz	4.40E-07	5.00E-07	440 nm/4400 Å	500 nm/5000 Å
Indigo	6.81E+14	7.14E+14	681 THz	714 THz	4.20E-07	4.40E-07	420 nm/4200 Å	440 nm/4400 Å
Violet	7.14E+14	7.89E+14	714 THz	789 THz	3.80E-07	4.20E-07	380 nm/3800 Å	420 nm/4200 Å
Near ultraviolet (UVA or long wave/"blacklight")	7.89E+14	9.52E+14	789 THz	952 THz	3.15E-07	3.80E-07	315 nm/3150 Å	380 nm/3800 Å
Near ultraviolet (UVB or medium wave)	9.52E+14	1.07E+15	952 THz	1070 THz	2.80E-07	3.15E-07	280 nm/2800 Å	315 nm/3150 Å
Near ultraviolet (UVC or short wave)	1.07E+15	1.50E+15	1070 THz	1500 THz	2.00E-07	2.80E-07	200 nm/2000 Å	280 nm/2800 Å
Extreme or Vaccuum ultraviolet	1.50E+15	3.00E+16	1500 THz	3000 THz	1.00E-08	2.00E-07	10 nm/100 Å	200 nm/2000 Å
X-rays	3.00E+16	3.00E+18	30 PHz	3 EHz	1.00E-10	1.00E-08	0.1 nm/100 pm	10 nm/100 Å
Gamma rays	2.42E+18	...and up	2.42 EHz	…and up	1.24E-10	…and shorter	124 pm	…and shorter

Calculate the energy and wavelength for radio stations with the following frequencies (assume all digits given are significant):

	Energy (J)	Wavelength (m)
1. 104.3 MHz	________	________
2. 660 kHz	________	________
3. 94.5 MHz	________	________
4. 15000. kHz	________	________
5. 1000. kHz	________	________
6. 91.3 MHz	________	________
7. 93.3 MHz	________	________
8. 1520. kHz	________	________

Calculate the energy and frequency for the following waves (use normal s.d. rules)

	Frequency (Hz)	Energy (J)
1. 650. nm	________	________
2. 417 nm	________	________
3. 58 μm	________	________
4. 1.854 cm	________	________
5. 54.55 mm	________	________
6. 1.112 km	________	________
7. 4533.2 Å	________	________
8. 6700. Å	________	________

Will an electron be ejected from a piece of these metals given the photon energy below? If so, give the energy of the electron when ejected.

	Photon E (eV)	Y/N	e^- Energy (eV) – if applicable
1. copper	4.5 eV	________	________
2. cesium	2.3 eV	________	________
3. platinum	6.8 eV	________	________
4. silver	3.1 eV	________	________
5. uranium	3.9 eV	________	________

Graphing Exercise – Calculator

The following data were gathered after frequency and wavelength measurements were made on a variety of waves.
Answer the questions that follow for EACH graph!

Frequency (Hz)	Wavelength (m)
3.47E+17	8.65E-10
3.05E+17	9.84E-10
2.40E+17	1.25E-09
1.15E+17	2.61E-09
8.26E+16	3.63E-09
5.99E+16	5.01E-09
4.79E+16	6.26E-09

Calculator portion:
Use a TI graphing calculator to answer the following questions (I have based these instructions using a TI-83 plus).

1. Press 2nd and MEM. Select number 2 to delete any preexisting lists.
2. Move the arrow to choice 4 (List) and press ENTER. Press DEL until no lists remain.
3. Press the STAT button on the calculator.
4. Press ENTER when the EDIT menu is highlighted.
5. You will see Name= at the bottom of the screen. Enter FREQ and press ENTER. Press the → button. Enter WAVE and press ENTER.
6. Go back to FREQ(1) and begin entering the time data.
7. Press → and repeat with the mass data under WAVE(1).
8. Press 2nd and QUIT. Once on the main screen, press 2nd STAT PLOT (above Y=).
9. Press ENTER on Plot1.
10. Highlight On (Off is the default) and press ↓.
11. Next to Type: make sure the scatterplot (1st option) is darkened. Press ↓ again and type FREQ next to Xlist.
12. Press ↓ and type WAVE next to Ylist. This will produce a scatterplot of Wavelength vs. Frequency (y vs. x).
13. Press ZOOM. Select ZoomStat to give a window size that will best-fit your scatterplot points. Since all of your data is in the first quadrant, you may want to set Xmin and Ymin to 0 (do this by pressing WINDOW).
14. Press GRAPH to view these points.
15. Press STAT and then CALC. Scroll down to PwrReg and press enter. Press 2nd LIST, select WAVE. Press the comma button and press 2nd LIST again. Select FREQ and press ENTER
16. Press ENTER and wait for the y=, a=, and b= to appear. Copy this data below.
17. Press Y= and ENTER use the format of the PwrReg function to enter the equation the regression gives you. Make sure to substitute the a and b values given! Press GRAPH. Note how the regression gives the equation for the best-fit function.

1. What kind of proportionality is displayed?
2. What is the proportionality constant?
3. What is the significance of this constant (i.e. what does it represent)?
4. Determine the wavelengths at the following frequencies:
   Do this by pressing VARS. Move to the Y-VARS menu and select function. Select Y1 since your best-fit curve's equation is in Y1. To determine the desired wavelength, enclose the frequencies below in parentheses after Y1.
   a. 4.55×10^4 Hz
   b. 1.223×10^9 Hz
   c. 9.32×10^{11} Hz
   d. 7.344×10^{15} Hz

Consider the data below for various photon energies:
Clear the lists above and Y1 (or use L3, L4, and Y2) and repeat the procedure above.

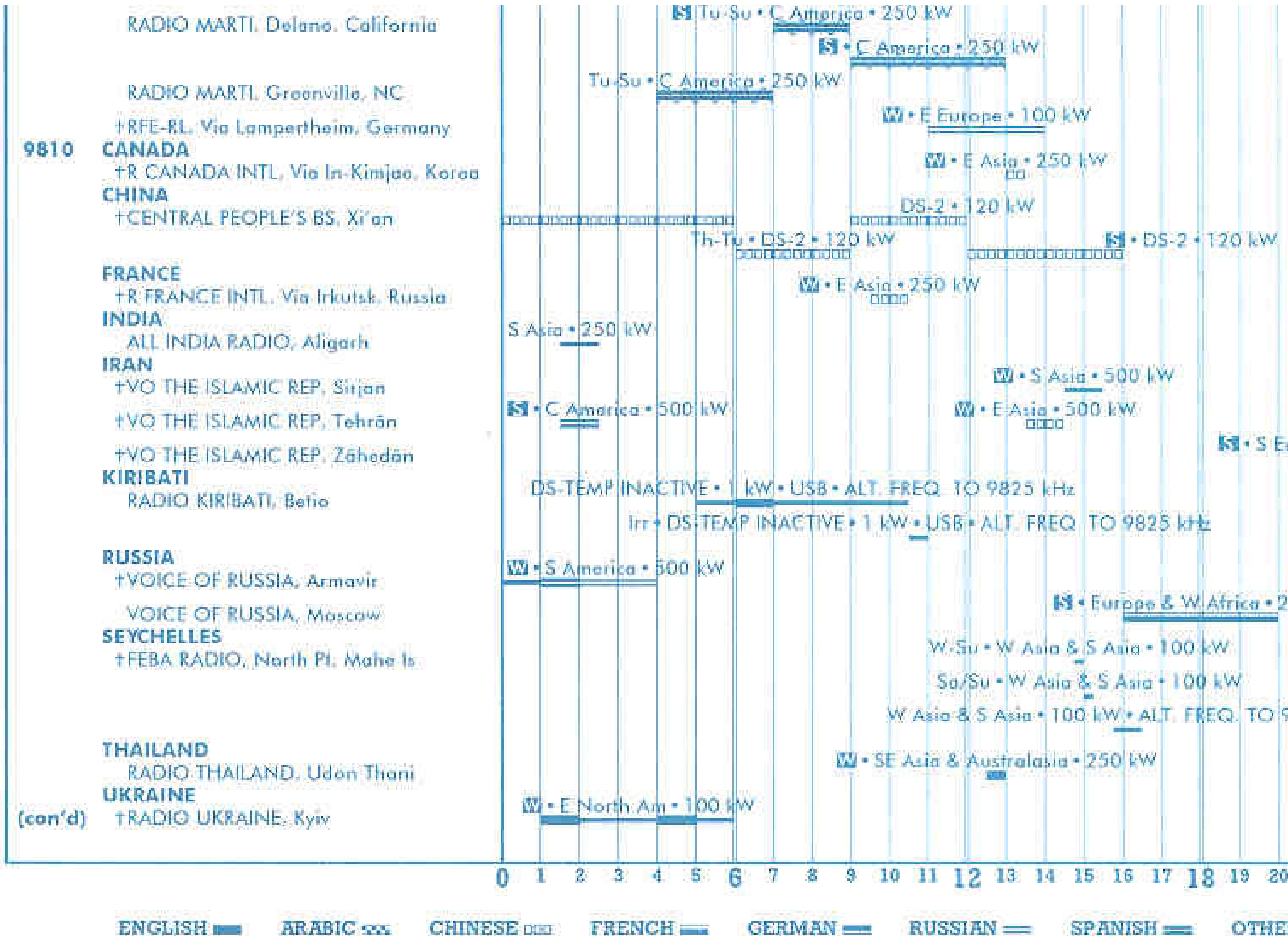
Frequency (Hz)	Energy (J)
6.04E+07	4.00E-26
6.86E+07	4.55E-26
8.13E+07	5.39E-26
9.04E+07	5.99E-26
1.05E+08	6.96E-26
1.88E+08	1.25E-25

1. What kind of proportionality is displayed? Will you use PwrReg for this data?
2. What is the proportionality constant?
3. What is the significance of this constant (i.e. what does it represent)?
4. Determine the energies of radiation with the following frequencies:
   a. 8.55×10^6 Hz
   b. 8.223×10^8 Hz
   c. 4.389×10^{12} Hz
   d. 5.346×10^{18} Hz

Draw an energy level diagram below with the following values:

$E_1 = 0.00$ eV	$E_2 = 1.86$ eV	$E_3 = 2.82$ eV	$E_4 = 3.56$ eV
$E_5 = 4.11$ eV	$E_6 = 4.48$ eV	$E_7 = 4.62$ eV	$\phi = 4.70$ eV

1. Draw a ground state electron.
2. The electron is excited to the fourth energy level.
3. Determine the energy of the photon required to excite this electron. __________
4. This electron relaxes to the second energy level.
5. Draw the photon that is released and determine the energy of this photon. __________
6. Determine the frequency of this photon. __________
7. Determine the wavelength associated with this radiation. __________
8. The electron is now excited to the seventh energy level.
9. Determine the energy of the photon that excited the electron. __________
10. The electron relaxes to the ground state.
11. Radiation with a wavelength of 348.5 nm strikes this electron. Will this exceed the work function of the metal? Explain your answer in the space below and graphically on the diagram.



12. The American broadcast "Radio Marti" to Central America experiences jamming. Jamming occurs when the governing body of the target audience does not want its people to listen to a transmission from another region. It was very popular during the Cold War, and it is still practiced today by some governments. If the American transmission is on a frequency of 9805 kHz, what is the wavelength of the signal being generated by the "jammer?"

13. How many waves are transmitted during the entire broadcast by Radio Ukraine?

14. Which signal travels faster: Radio France International's signal to Russia or Iran's Voice of the Islamic Republic broadcast to Southeast Asia? Explain your answer.

15. Calculate the energy of the waves of the stations that transmit on this frequency.

16. Calculate the number of waves that are transmitted during Voice of Russia's French language portion.

Construct the Energy Level Diagram:

1. An electron relaxing to the ground state from E_5 gives off light at a wavelength of 415.8 nm.

2. A second electron relaxes from E_5 to E_2 giving off a wavelength of 748.1 nm.

3. An electron is ejected from this atom with an energy of 0.2421 eV when irradiated with a frequency of 8.30×10^{14} Hz.

4. A ground state electron can move to E_3 with a photon of at a frequency of 5.509×10^{14} Hz.

5. The difference between E_5 and E_4 is 0.2497 eV.

6. An electron falling from E_6 to E_2 gives off light with a length of 6997 Å.

When asked if a certain quantum number's value is plausible in a given scenario consider the following points:

n	Sublevels (ℓ)	Number of Orbitals (m_ℓ)	Total Electrons
1	0 (s)	0 → **1**	$1 \times 2\ e^- = 2\ e^-$
2	0,1 (s, p)	0 → 1 -1,0,1 → 3 1 + 3 = **4**	$4 \times 2\ e^- = 8\ e^-$
3	0,1,2 (s, p, d)	0 → 1 -1,0,1 → 3 -2,-1,0,1,2 → 5 1 + 3 + 5 = **9**	$9 \times 2\ e^- = 18\ e^-$
4	0,1,2,3 (s, p, d, f)	0 → 1 -1,0,1 → 3 -2,-1,0,1,2 → 5 -3,-2,-1,0,1,2,3 → 7 1 + 3 + 5 + 7 = **16**	$16 \times 2\ e^- = 32\ e^-$
5	0,1,2,3,4 (only 0 – 3 are observed!) Therefore, only s, p, d, f	Quantum theory: 0 → 1 -1,0,1 → 3 -2,-1,0,1,2 → 5 -3,-2,-1,0,1,2,3 → 7 -4,-3,-2,-1,0,1,2,3,4 → 9 1 + 3 + 5 + 7 + 9 = **25** Observed: 0 → 1 -1,0,1 → 3 -2,-1,0,1,2 → 5 -3,-2,-1,0,1,2,3 → 7 1 + 3 + 5 + 7 = **16**	Quantum theory: $25 \times 2\ e^- = 50\ e^-$ Observed: $16 \times 2\ e^- = 32\ e^-$
6	0,1,2,3,4,5 (only 0 – 3 are observed!) Therefore, only s, p, d, f	Quantum theory: 0 → 1 -1,0,1 → 3 -2,-1,0,1,2 → 5 -3,-2,-1,0,1,2,3 → 7 -4,-3,-2,-1,0,1,2,3,4 → 9 -5,-4,-3,-2,-1,0,1,2,3,4,5 → 11 1 + 3 + 5 + 7 + 9 + 11 = **36** Observed: 0 → 1 -1,0,1 → 3 -2,-1,0,1,2 → 5 -3,-2,-1,0,1,2,3 → 7 1 + 3 + 5 + 7 = **16**	Quantum theory: $36 \times 2\ e^- = 72\ e^-$ Observed: $16 \times 2\ e^- = 32\ e^-$

Notice the number of orbitals equals n^2 and the total number of electrons on the level equals $2n^2$. Remember when filling a sublevel, the electrons may go to any orbital in that sublevel, so long as no orbital has two electrons before any other has one:

<u>Exercises</u>

1. Are the following four quantum numbers allowed according to quantum theory? Are there any combinations that are allowed by theory, but not observable? Explain all answers.

   a. $n = 7$ $\ell = 5$ $m_\ell = 4$ $m_s = -½$

   b. $n = 3$ $\ell = 0$ $m_\ell = -1$ $m_s = +½$

   c. $n = 2$ $\ell = 2$ $m_\ell = 2$ $m_s = +½$

   d. $n = 3$ $\ell = 1$ $m_\ell = 0$ $m_s = 0$

   e. $n = 4$ $\ell = 1$ $m_\ell = -3$ $m_s = -½$

   f. What elements could have electrons in the ground state with the quantum numbers: n = 2, = 0, m = -1, m = +½?

2. Is it true that as the energy of an electron increases, so will its distance from the nucleus?
3. Complete the above chart for n = 7.
4. Without writing out each set of quantum numbers, determine the total possible number of sublevels for a tenth energy level.
5. Similar to number four, how many orbitals would be present in a twenty-sixth energy level?

Lab – Atomic Emission Spectroscopy

Objective: To observe the visible spectra of various gases. To calculate the transitions and colors produce by hydrogen according to Bohr's model of the atom.

Materials:

Equipment:
Power supply, diffraction glasses

Procedure:
Place a diffraction grating in front of your eye as if it were slide and rotate until you can observe the spectrum lines on either side of the discharge tube. Record the colors and lines you see in a data table such as the one given below.

Example:

Gas	Spectrum 1	Spectrum 2	Spectrum 3	Spectrum 4
Sample	R(2f1d) O(3d) V(2m)	Bl(3m)		

In the above example, lines are seen in two different spectra. The spectra that appears closest to the discharge tube (#1) features 3 red lines –2 faint and 1 dark. There are also 3 dark orange lines and 2 moderate violet lines.

You may want to setup a data table in advance. It is recommended you hold your notebook horizontally. Leave plenty of space between gases.

Analysis/Calculations:

1. Use the equation $\frac{1}{\lambda} = \frac{E}{ch}\left(\frac{1}{n_f^2} - \frac{1}{n_i^2}\right)$ to determine the wavelength of the light produced by each transition in a hydrogen atom (there are 21 total). E is a constant that represents the total amount of energy needed to remove an electron from a hydrogen atom and is equal to 2.176×10^{-18} J. As always, c represents the speed of light and h is Planck's constant. The variable n_i represents the initial energy level (the level the electron started on), and n_f is the final energy level to which the electron falls.

   For example, if an electron falls from the 4th to the 2nd energy level, the substitution will look like this:

   $$\frac{1}{\lambda} = \frac{E}{ch}\left(\frac{1}{2^2} - \frac{1}{4^2}\right)$$

Remember that once you simplify the equation you will find $\frac{1}{\lambda}$, **not** λ. Let's say you find $\frac{1}{\lambda}$ = 3.21 × 10^7; then $\lambda = \frac{1}{\lambda}^{-1}$ = (3.21 × 10^7)$^{-1}$ or 3.11 × 10^{-8} m = 31.1 nm.

You will perform this calculation for each of the following series:

a. excited states to the first energy level (6 transitions)
b. excited states to the second energy level (5 transitions)
c. excited states to the third energy level (4 transitions)
d. excited states to the fourth energy level (3 transitions)
e. excited states to the fifth energy level (2 transitions)
f. E_7 to E_6 (1 transition)

3. Use the electromagnetic spectrum in your text or elsewhere to match the color seen with its corresponding transition. Be aware that many sources will list wavelengths of light in nm, **not meters!**
4. Compare the Rydberg constant (it's in your handbook) to $\frac{E}{ch}$. What do you find?

Conclusion:

1. What are the names for the transitions in a hydrogen atom for:
   a. excited states to the first energy level
   b. excited states to the second energy level
   c. excited states to the third energy level
   d. excited states to the fourth energy level
   e. excited states to the fifth energy level

   Indicate if these colors were observed or not.
   You may need to look up phrases like "hydrogen line spectra" or "emission series names" to get the names of these transitions.

2. Speculate as to ***why*** you may have seen (or possibly failed to see) colors in the hydrogen tube that were not predicted (by the calculations) to be part of the spectrum for hydrogen.
3. When you see a pink "neon" light in a store, is your eye truly seeing an electron transition that produces a pink photon? Explain.
4. The hydrogen discharge tube becomes very hot in a short period of time. Based on the colors you determined were present, give a reason for this intense heat.

1. Differentiate between photoluminescence and incandescence.

2. Which receptors in our eyes are stimulated when we see yellow?

3. What does a piece of cloth do to the colors in white light that is shined on it?

4. What would happen to plants if only green light was shined on it?

5. On a computer, what colors could be seen from the RGB sequence:

   a. (128, 128, 128)
   b. (255, 150, 0)
   c. (0, 0, 128)
   d. (255, 255, 0)

6. What color would carrots be if carotenoids absorbed light between 380 nm and 400 nm as well as from 500 nm and 750 nm?

7. Explain how the honeybee's ability to see green, blue, and ultraviolet may be responsible for it repeatedly flying into a window when it is trapped in a room.