Name ________________________________**Chem 162, Section**: _______**Team Number:** ______

ALE 1. The Wave Nature of Light and Atomic Structure

(Reference: Sections 7.1 and 7.2 - *Silberberg 5th edition*)

> **Important!!** For answers that involve a calculation you must show your work neatly using dimensional analysis with correct significant figures and units to receive full credit. No work, no credit. Report numerical answers to the correct number of significant figures. **CIRCLE ALL NUMERICAL RESPONSES**.

How are the wavelength and frequency of light related?

Welcome to CHEM 162! In this class, you will work in small groups in order to learn course content as well as develop the general skills of problem solving, communication (both written and verbal), time management, and how to work effectively with your peers.

I have more-or-less randomly determined who your teammates will be (at least for a couple of class sessions). You should begin by learning who your teammates are.

Exercise A: ♬ "Getting to know you . . ." ♬

Spend a couple of minutes introducing yourselves to each other. In addition to your name, tell your teammates: (1) what your major is (or just say whether you think you're interested in one of the sciences if your major is now "undeclared"); (2) what year you are in at GRCC ("freshman", "sophomore", *etc*.); and (3) what your initial impression of Chemistry is and why.

Exercise B: Role playing

To help your team work efficiently and smoothly each class session, you will have an assigned role. Each role within a team is vitally important to the team's success (*i.e.*, to learn chemistry), but not everyone within the team will have the same "job description". How are the team roles alike? You will all be active participants in the learning process. How are the team roles different? Let's find out!

Your instructor will explain how you can find out what each of your roles is for today's session. Next, read the below table.

Title	Duties
1. Manager	Actively participates in team discussions, keeps the team on task, distributes work and responsibilities, resolves disputes, assures that *all* team members participate and understand the activity the team is working on
2. Recorder	Actively participates in team discussions and keeps a written record of the team's work by completing in the "***Recorder's Report***" as the team formulates responses while working collaboratively on an activity in class.
3. Spokesperson	Actively participates in team discussions, communicates to the other teams orally or in writing (*e.g.*, on the classroom's whiteboard), represents the team when interacting with the instructor and other teams in the classroom. If *anyone* on the team has a question for the instructor, for another team, the class etc., the spokesperson asks it.
4. Strategy Analyst	Actively participates in team discussions, reflects on the team's performance by assessing whether they are using their time effectively or if they ought to adopt a different strategy; identifies what the team is doing well, what needs improvement, and insights and discoveries individual and team performance by completing the "***Strategy Analyst's Report***."

To the best of your ability, in <u>your own words</u> (but you may refer back to this sheet if you need to) tell each other what you perceive is your job. Each of you should respond, adding to your teammates perceptions, clarifying, even disputing if need be.

It will take you a while to become comfortable with what each of these roles entails—perhaps even more time to get comfortable playing out each of these roles. But practice is the key, so let's get started! *Review the following **Model** and then answer the **Key Questions** and **Exercises** that follow the model.*

The Model: Wavelength and Frequency

Diffraction is the bending of a wave pattern around an obstacle. Light undergoes diffraction, thus we know that light has a wave nature.

The below figure represents a portion of a wave pattern having a constant **wavelength** (which is symbolized by the lowercase Greek letter "lambda", λ). The wavelength is the distance between consecutive crests (or troughs, or any two points that are one **cycle** apart from each other). The wavelength is related to the color of visible light (see The wave pattern might extend indefinitely to the left and to the right, but here only $3^1/_2$ cycles are shown. The wave's **amplitude** is shown on the *y*-axis and is a measure of the intensity of the wave—e.g. the bright a light wave is or how load a sound wave is. The wave's **baseline** (shown as a dashed horizontal line segment) is coincident with an amplitude of zero.

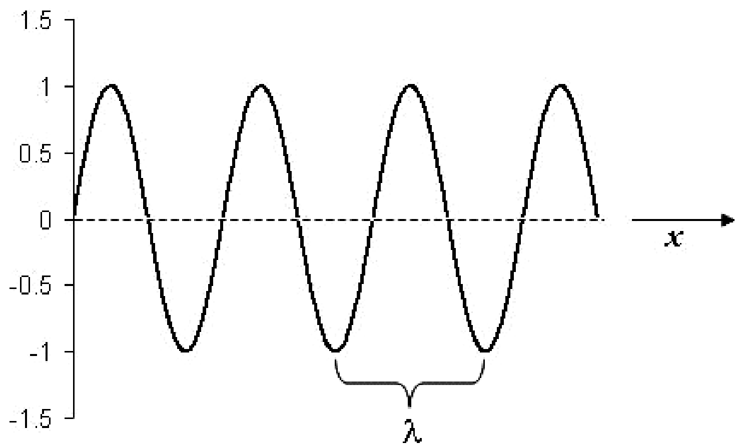


Figure 1. A representation of a portion of a wave with wavelength, λ, propagating through space.

Key Questions

1a.) *<u>On top</u>* of the existing wave in the figure above, trace out <u>one cycle</u>. (It really does not matter where you choose to begin or end the tracing of the cycle. It would be best to use something other than a black pen so that we can see what you have sketched.)

b.) In the figure above, the wavelength is pointed out between two troughs of the wave. Rather than two consecutive crests or troughs, identify two other points on the above figure the distance between which defines the wavelength. Draw a line segment between those two points and write a lambda next to the line segment.

2. It is well known that the relationship between the distance ***d*** traveled by an non-accelerating object with speed ***s*** in the amount of time ***t*** is given by $\boldsymbol{s} = {}^{\boldsymbol{d}}/_{\boldsymbol{t}}$ (**eq 1**).What property of a wave pattern corresponds to ***d*** in the mathematical definition of speed? (*<u>Circle the correct response</u>*.)

i. amplitude	iii. cycle	v. intensity
ii. baseline	iv. frequency	vi. wavelength

Model

Imagine a wave pattern moving past a fixed point (represented by the horizontal line).

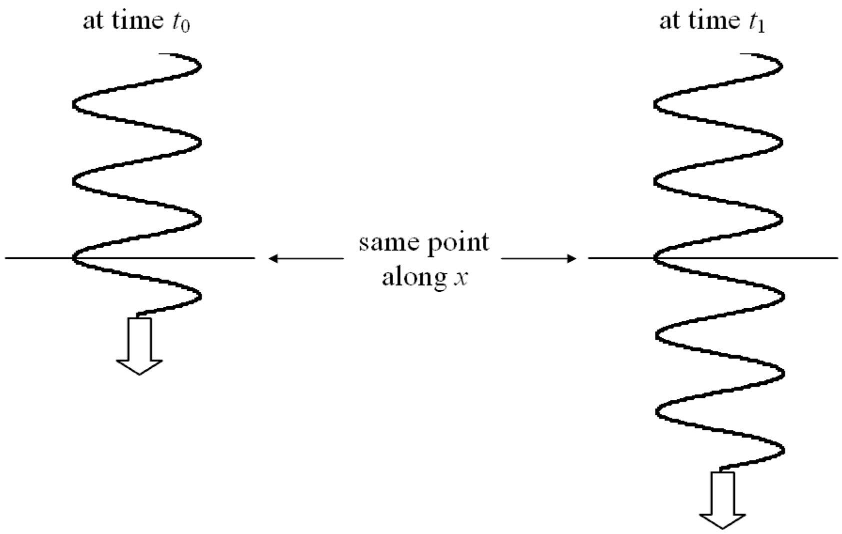


Figure 2. A representation of a portion of a wave with wavelength, λ, propagating through space at time t_o and at a later time, t_1.

The wave's **frequency** (symbolized by the lowercase Greek letter "nu", ν) is the <u>*number of cycles that pass a given fixed point per unit time*</u>. The ***units of frequency*** are:

$$\frac{\textbf{cycles}}{\textbf{s}} = \frac{\textbf{1}}{\textbf{s}} = \textbf{s}^{\textbf{-1}} = \textbf{Hz} = \textbf{“hertz”}$$

(The unit "cycle" is one of those that can be added or taken away whenever it is convenient.)

Key Question

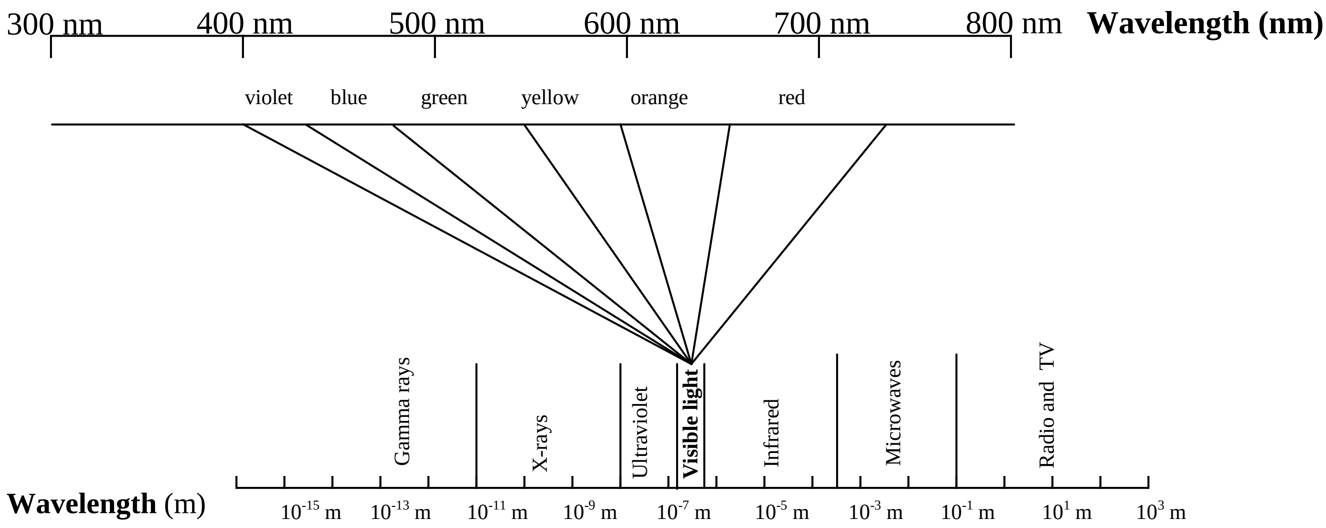
3a.) How is time related to frequency?

b.) How might the symbol ν be incorporated instead of ***t*** in the formula for speed (**eq 1**)?

c.) Rewrite the speed formula ($s = {}^{d}/_{t}$) using the symbols λ and ν instead of ***d*** and ***t***.

S **=** **(eq 2)**

The Model: Electromagnetic Radiation as Waves



1 m = 10⁹ nm (“nanometer”)

Figure 3. Regions of the electromagnetic spectrum. Note that gamma rays and x-rays have very short wavelengths, while radio and TV waves have long wavelengths. The relatively narrow region of visible light is expanded with wavelengths given in nanometers.

The term “light” applies equally to radio waves, microwaves, infrared light, visible light, ultraviolet light, X-radiation, and γ-radiation. What differentiates one form of EM radiation from another is the wavelength (and frequency) of the light wave. However, they are all part of the *electromagnetic spectrum*. **Electromagnetic radiation** (abbreviated **EMR**) takes the form of self-propagating waves. EM radiation gets its name because it has an electric field and magnetic field components which oscillate *in phase* perpendicular to each other and to the direction of energy propagation.

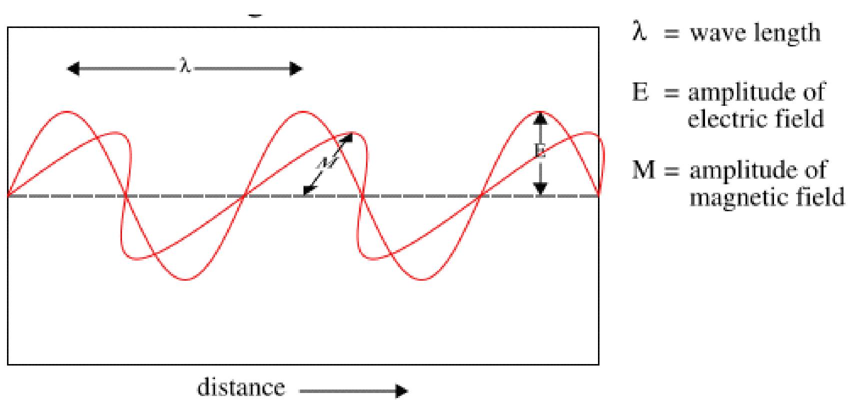


Figure 4. A representation of the electric and magnetic fields of a portion of EMR with wavelength, λ, propagating through space. Note that the electric field component (within the plane of the paper) and the magnetic field component (perpendicular to the plane of the paper) are in phase and are perpendicular to each other.

Table 1. Wavelengths and frequencies of some specific examples of electromagnetic radiation

EM Radiation	λ (nm)	ν (s^{-1})	s ($m \cdot s^{-1}$)
KGRG radio waves (89.9 MHz on your dial)	3.33×10^{9}	8.99×10^{7}	
Radiation of microwave oven	1.20×10^{8}	2.50×10^{9}	
IR frequency used by a TV remote control	931	3.22×10^{14}	
Yellow light given off by a Na vapor lamp (public lighting)	589	5.09×10^{14}	
Violet light absorbed by chlorophyll during photosynthesis	440.	6.81×10^{14}	
A wavelength of UV-B (which is absorbed by O_3 in the stratosphere)	280.	1.07×10^{15}	
α radiation used in X-ray crystallography	1.54×10^{-1}	1.95×10^{18}	
photon from annihilated electron	2.42×10^{-3}	1.24×10^{20}	

Key Question

4a. Use **eq 2** (*i.e.*, the formula you derived in Key Question 2d) to calculate the speed (**in m/s**) to 3 significant figures for each of the types of radiation in Table 1. Show below a sample calculation for the speed of a KGRC radio wave and enter the speeds of the other waves in Table 1. *Circle your answer*.

b.) The speed of light is given *c* as a special symbol (rather like the gas constant is given the special symbol *R*). *Briefly explain why the speed of light is given a special symbol*.

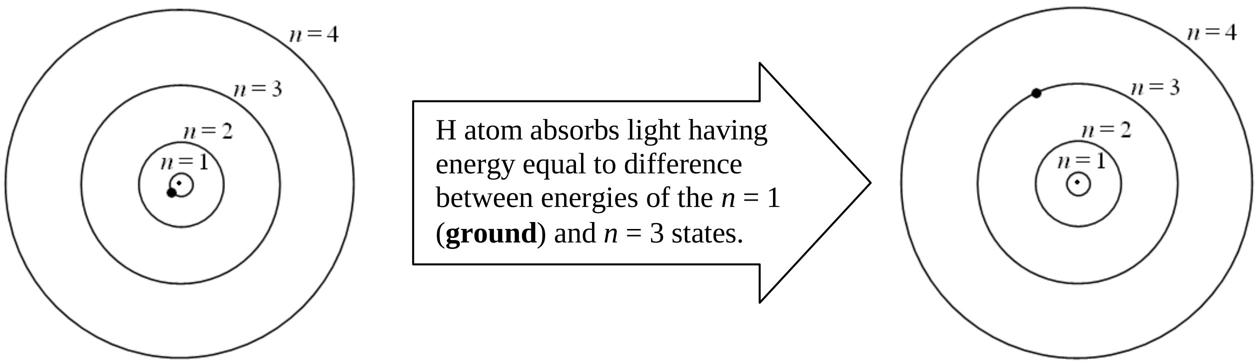
Exercise

A. Complete the following table:

λ (nm)	ν (s^{-1})	Region of the EM spectrum
5.00×10^{-7}		
	6.68×10^{17}	
3.85×10^{-5}		
	1.04×10^{6}	

The Model: The Bohr Model and Atomic Emission Spectra

The **Bohr model** of the hydrogen atom was the first **quantized** model of an atom. The Bohr model is able to successfully explain why the hydrogen atom has the absorption/emission spectrum that it does. No previous model of the atom could explain absorption/emission spectra. The Bohr model of the hydrogen atom involved the single electron orbiting around the tiny central nucleus (a proton). The electron could only exist in one of the various **quantized** energy levels, each level having a different **quantum number *n*** with its associated radius. The electron could not exist between these fixed states. (An analogy to this is how you cannot plant your foot between rungs on a ladder, but only on the rungs, which have fixed positions on the ladder.) When the hydrogen atom accepts the energy of light, the electron becomes **excited**.

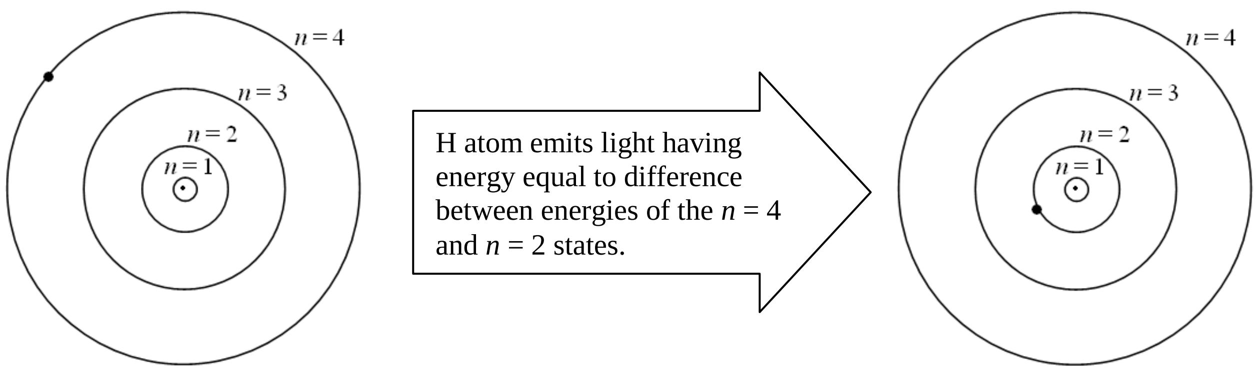


Initial state of H-atom **Final state of H-atom after absorption of light**

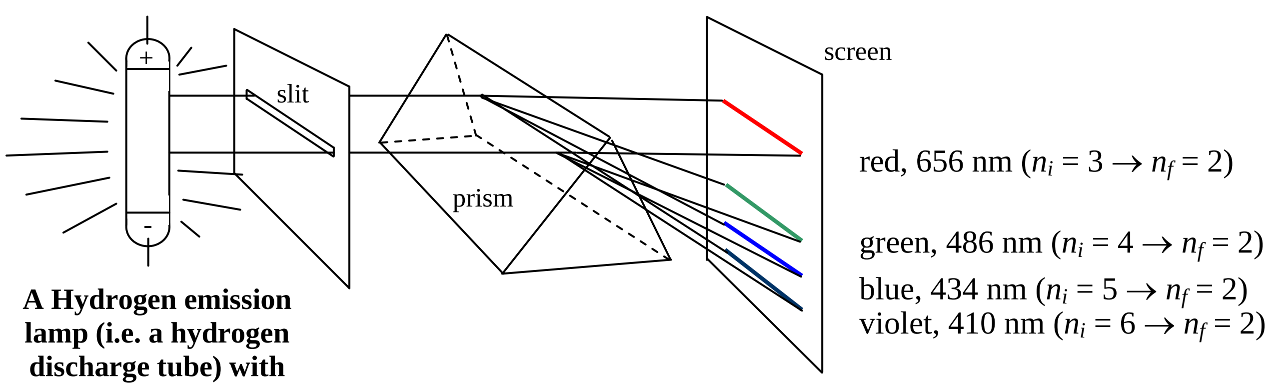
(Note: States with $n > 4$ do exist, but are not shown)

• = electron in orbit about nucleus, ·

When an excited hydrogen atom de-excites, the extra energy is emitted as light as the electron returns to a lower energy level—in this case the ground state, n = 1.



Initial "excited" state of H-atom **Final state after electron returns to ground state, n = 1**



A Hydrogen emission lamp (i.e. a hydrogen discharge tube) with hydrogen atoms in various excited states

Hydrogen's emission spectrum of wavelengths of light that are visible to human eye

Key Questions

5. In your own words, what is meant by the term "quantized"? [*e.g.*, What does it mean for the distance between the electron and the nucleus (thus the electron's energy) to be quantized?]

6a.) What charge does an electron have? ____________________ a proton? _____________________

b.) Which is more stable, an electron close to or far away from the nucleus? (Circle the correct choice.)

c.) What is the relationship between the energy of an electron and its distance away from the nucleus?

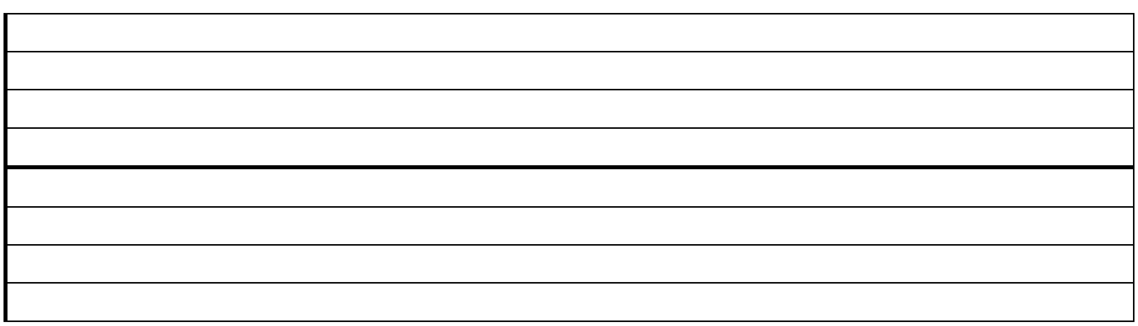
7. Explain why the emission spectrum of the hydrogen atom consists of a number of lines, each having a different color. (The wavelength of light is related to the energy of light.)

Exercises

B. Problem 7.8 (modified):

a.) An FM radio station broadcasts classical music at 93.5 MHz (megahertz = 10^6 Hz). Calculate the wavelength in meters (m), nanometers (nm) and Angstrom (Å) of the radio waves broadcasted by this station. *Circle your answers*.

b.) Draw on the graph below two representations of the waves broadcasted from this station, one at a low volume and another that is in phase with the 1^{st} wave, but twice its volume. *Starting each wave at the origin*, make each wave *two wavelengths long*. Label the wavelength and amplitude of each wave.



C. Problem 7.12: Using only the information provided below, rank the following photons in order of decreasing energy. ***Explain*** the basis for your ranking:

a.) Infrared, IR ($\nu = 6.5 \times 10^{13}\ s^{-1}$); b.) Microwave ($\nu = 9.8 \times 10^{11}\ s^{-1}$); c.) Ultraviolet, UV ($\nu = 8.0 \times 10^{15}\ s^{-1}$)

Highest energy ⟶ **Lowest energy**

____

Explanation:

D. Problem 7.14 (modified): Each covalent bond in a molecule vibrates at a specific frequency in the IR region—think of each vibration as two balls (atoms) attached to a spring (covalent bond) bouncing back and forth at a specific frequency. Consequently, each covalent bond in a molecule absorbs a specific frequency of radiation in the IR region equal to the frequency at which it vibrates.

a.) Carbon—oxygen bonds in organic compounds absorb radiation with a wavelength of 9.6 μm. Calculate the frequency (in s^{-1} and Hz) of the radiation absorbed by C—O bonds. At what frequency do the carbon and oxygen atoms vibrate? *Circle your answer*.

b.) In hydrogen chloride, the H—Cl bond has a vibrational frequency of 8.652×10^{13} Hz. Calculate the *wavelength in μm* of the radiation that this bond absorbs. *Circle your answer*.