Learning Objectives and Worksheet I

Chemistry 1B-AL Fall 2016

~~Lectures~~ (1-2) Nature of Light and Matter, Quantization of Energy, and the Wave-Particle Duality

Read: Chapter 12, Pages: 524-526
Supplementary video: The History of Atomic Chemistry: Crash Course Chemistry
Link: http://youtu.be/thnDxFdkzZs

I. Understand the following aspects of the laws of physics circa 1900, which were successful for describing large objects (i.e. particles) and electromagnetic waves:

1. Be able to identify the following fundamental particles, their respective charges, and their relative masses *(high school review?? learned on MOM's knee in your childhood??)*

- **i.** Electron
- **ii.** Proton
- **iii.** Neutron

2. What are three properties that were considered by 19th century physicists to be exclusively 'properties of particles'?

- **i.** ________________________
- **ii.** ________________________
- **iii.** __________________________

3. What are three characteristics or properties that were considered by 19th century physicists to be exclusively 'properties of waves?

- **i.** ____________________________
- **ii.** ____________________________
- **iii.** ____________________________

4. Waves (sound, water, electromagnetic, etc.) are characterized by several properties

- **i.** Wavelength (λ): the _________________________ between successive maxima or minima
- **ii.** Frequency (ν): the number of ________________________ per unit time
- **iii.** Amplitude (A): the deviation from an ______________________ level
- **iv.** For an electromagnetic wave (e.g. light, etc.), the amplitude A represents the strength of the ______________________ and ______________________ fields and A^2 the __________________ of the radiation
- **v.** Wavelength and frequency are _________________ variables, meaning you could calculate one if you know the value of the other using $\lambda\nu = c$.

In a vacuum an electromagnetic wave travels with a velocity = 2.9979×10^8 ms^{-1}

For more information on electromagnetic radiation and interactive Java tutorial:
https://micro.magnet.fsu.edu/optics/lightandcolor/electromagnetic.html

5. Know the types of radiation found at various frequencies of electromagnetic radiation and their relative ordering (as a function of wavelength)

i. ____

ii. ____

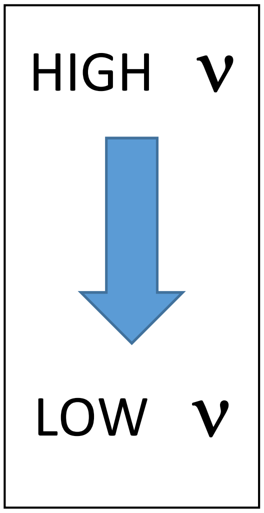
iii. ____

iv. ____

v. ____

vi. ____

vii. ____



6. Visible electromagnetic radiation fall correspond to wavelengths

____________ nm (short) to ____________ nm (long). The colors perceived at these wavelengths are classically categorized as:

(short λ) _____________ ______________ ______________ ______________ (~550nm)

_____________ ______________ _______________ (long λ)

7. Understand the following terms, relationships, and phenomena. Which of these were associated with the classical concept of particles, which with classical electromagnetic waves, and which with both (in classical models); circle the correct answres? *[most important are in **bold**].*

i. **Kinetic energy** (K.E.= _______*)* *[particle, wave, or both?]*

ii. **Potential energy** (e.g. electrostatic pull, gravitation, stretched spring)

[particle, wave, or both?]

iii. **Conservation of energy** *[particle, wave, or both?]*

iv. **Relation between frequency and wavelength** $\lambda\nu=$ ____ *[particle, wave, or both?]*

v. **Momentum** (momentum p=mv) *[particle, wave, or both?]*

vi. Newton's laws of physics (F=ma) *(will study in physics 6)*

[particle, wave, or both?]

vii. Maxwell's Laws *(will study in physics 6; describes electromagnetic waves)*

viii. Dispersion *[particle, wave, or both?]*

ix. Refraction *[particle, wave, or both?]*

For more info and a Java tutorial on refraction:
https://micro.magnet.fsu.edu/optics/lightandcolor/refraction.html

x. Diffraction *[particle, wave, or both?]*

More info/Java tutorial:
https://micro.magnet.fsu.edu/optics/lightandcolor/diffraction.html

HW #1 1, 2, 7

xi. **Interference** (constructive and destructive) *[particle, wave, or both?]*

More info/Java tutorial:
https://micro.magnet.fsu.edu/optics/lightandcolor/interference.html

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Introduction: Between 1887 and 1927 experiments indicated that the distinctions between particles and waves were less clear cut than previously postulated

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II. Understand the following observations and their implications regarding the deficiencies of the classical physics model

1. Photons:

i. Experiment: **BLACKBODY RADIATION**

a. **What was observed?**
The intensity of radiation emitted by a heated ('glowing') black-body peaked at frequencies that increased with the temperature of the object, but always dropped off at higher (ultraviolet) frequencies.

b. **What was the contradiction to laws of classical physics?**
Classical physics predicted the Ultraviolet Catastrophe (not observed whew!) *[CHEM1Bsters: just get a qualitative idea; quantitative explanation is advanced topic!!]*

c. **What was the postulate that resolved contradiction?**
Electromagnetic energy was radiated in packets (photons) with fixed energies related to their wavelength Planck's law E_{photon}=______=hc/λ.
where h=6.626 × 10^{-34} m^2 kg s^{-1} Planck's constant.

d. Know how to find/calculate all variables in Planck's equation

ii. Experiment: **PHOTOELECTRIC EFFECT** (Einstein won Nobel Prize 1921 for interpretation of the Photoelectric Effect)

a. **What was observed?**

b. ***What was the contradiction to laws of classical physics?***
Light of short wavelengths would eject electrons from a materials, but at longer wavelengths no electrons would be ejected no matter how great the amplitude (i.e. the intensity or the power) of the light beam
Be able to understand how the observation contradicted the classical theory of electromagnetic waves
Consider a model for the photoelectric effect to be an electron in a "potential well". Be able to state the outcome of the following experimental conditions based on what would be expected using the classical physics models, and what the actual observations were and their implications. State the relative number of electrons emitted and the velocity (K.E.) of the emitted electrons.

c. What classical physics would predict??

(1) Long wavelength, small amplitude electromagnetic wave

____

(2) Long wavelength, large amplitude electromagnetic wave

____

What was observed in terms of ejected electrons:

Wavelength of light	Intensity of light	Relative number of electrons (none/few/many)	Relative velocity of electrons (slow/fast)
long ($hc/\lambda < \Phi$)	weak	_______________	_______________
long ($hc/\lambda < \Phi$)	strong	_______________	_______________
medium (hc/λ just above Φ)	weak	_______________	_______________
short ($hc/\lambda >>> \Phi$)	weak	_______________	_______________
short ($hc/\lambda >>> \Phi$)	strong	_______________	_______________

d. ***What was the postulate that resolved contradiction?***

HW #1: 3, 4, 5

e. Be able to calculate the minimum energy to remove an electron from a "potential well" and the K.E. of any ejected electrons.

2. Energies of electrons in atoms are quantized:

i. Experiment: **SPECTRUM OF THE HYDROGEN ATOM**

a. ***What was the contradiction to laws of classical physics?***
According to classical electrodynamic theory the hydrogen atom should collapse almost instantly and give off radiation of all frequencies. However, the hydrogen atom does exist and Rydberg and others observed that hydrogen atoms emitted light at only certain frequencies.

b. ***What was the postulate that resolved contradiction?***

c. Understand how the line spectra could be understood in terms of Bohr's hypothesis. Know how to manipulate Bohr's relationship to calculate state energies, transition energies, quantum numbers of initial final states, and the frequency and wavelength of transitions.

Which transition would have the largest absorption energy:

HW #1: S1

a. $n_1 \rightarrow n_5$ **b. $n_2 \rightarrow n_5$** **c. $n_6 \rightarrow n_1$** **d. $n_5 \rightarrow n_6$**

Links for further information on the spectrum of hydrogen atom and an experiment simulation:
http://phys.educ.ksu.edu/vqm/html/emission.html
http://phys.educ.ksu.edu/vqm/html/absorption.html
http://phys.educ.ksu.edu/vqm/html/h2spec.html

3. “Particles” behaving like “waves”

i. Experiment: **Davisson and Germer scattered electrons from a Ni crystal and observed the resulting interference patterns (1921-1927). G.P. Thompson showed diffraction pattern from electrons passing through gold foil produced an interference pattern (1927).**
Davisson and Thompson won the Nobel Prize in 1937 for this work.

a. ***What was the contradiction to laws of classical physics*?**
When electrons (classical particles) are shot at slits they form an interference pattern. Whoooa, hold on there a moment!! Classically, interference and diffraction effects were considered to be phenomena that were associated only with waves, not particles.

HW #2: 8, 9

b. ***What was the postulate that resolved contradiction*?**
Louis de Broglie had postulated that electrons (and other “classical particles”) had wave-like properties (Phd Thesis 1924 and Nobel Prize 1929!). He derived that the wavelength of a particle was related to its mass and velocity (i.e. its momentum) by the equation $p \equiv mv =$________. Using this relationship for wavelength and the laws of “wave interference” one calculates exactly the diffraction pattern that Davisson and Germer observed for electrons!

c. Know how to find/calculate all variables in de Broglie’s equation relating the mass, velocity, and wavelength of particles. Understand why we don’t notice the wave-like properties of ‘every-day’ objects.

4. “Waves” behaving like “particles” *(actually “more of waves behaving like particles” since the quanta of radiation in the photoelectric effect may be thought to be examples of light with particle-like behavior)*

i. Experiment: **Compton scattering** (Arthur Compton, 1927 Nobel Prize): shot electromagnetic ‘waves’ (x-rays or gamma rays) at electrons and measured the recoil angles and velocities of the electron and wave *[i.e. their scattering].* **This experiment is not described in text but we mention it here for completeness. You will not be responsible for its details.**

HW #1: 6, S2

ii. Using special relativity, Einstein showed
(momentum)$_{\text{photon}}$ $\equiv p_{\text{photon}} = h/\lambda$ just like de Broglie particles $p_{\text{particle}} = h/\lambda$, YEAH!!!
Using this relationship and equations usually applied only to particles (e.g. conservation of momentum and energy) the scattering of light waves ≡ photons could be described quantitatively. If one assumed this momentum for the “waves”, the scattering obeyed the same equations as would a cue ball shot at a rack of billiard balls.

THUS: $p=h/\lambda$ for both electromagnetic waves (zero "rest mass") and particles (nonzero "rest mass") but $p \approx mv$ only for non-zero rest mass m

Links for further understanding of the wave-particle duality:

Primer and Java tutorial:
http://www.olympusmicro.com/primer/lightandcolor/particleorwave.html

Double-slit experiment simulation:
http://phys.educ.ksu.edu/vqm/html/doubleslit/index.html

Video explanation of double-slit experiment
https://www.youtube.com/watch?v=DfPeprQ7oGc

Read: Chapter 12, pages 540-542

III. **Measurement and the Uncertainty Principle** (consequences of wave-like properties)

1. Understand why the simultaneous precise measurement of the position and velocity of a particle is not possible (Heisenberg Uncertainty Principle, Nobel Prize 1932). The equation relating the uncertainty in position and velocity of an object is:

   in terms of uncertainty in momentum and position __________ $\geq \hbar/2$

   or for the uncertainty in velocity $\Delta v \geq$ ___________________

2. Why does one not observe consequences of the wave-like properties of macroscopic 'every day' particles with large masses and smallish velocities?

HW #2: 12

3. Understand the meaning of a "particle wave" (aka a wave function) in terms of the probability of measuring a value of its position.

   The ___________________________ of the particle wave corresponds to the probability of finding the particle at a given point in space.