

CH301 Fall 2008 Worksheet 2 Answer Key

1. From memory (to the best of your ability), write all regions of the electromagnetic spectrum discussed in class in order from longest to shortest wavelength.

TV, radio, microwave, infrared, visible, ultraviolet, X-ray, γ -ray, cosmic rays

2. Now write the same regions of the electromagnetic spectrum in order from highest to lowest energy.

Cosmic rays, γ -ray, X-ray, ultraviolet, visible, infrared, microwave, radio, TV

Remember, $E = h\nu = hc/\lambda$. In other words, energy (E) is inversely proportional to wavelength (λ) and so longer wavelengths correspond to lower energies; thus the order is reversed relative to question 1.

3. If asked to write the spectrum in order from highest to lowest frequency, would they be written in the same order as in question 1 or question 2? Explain your reasoning.

The spectrum would be written in the same order as question 2. Remember, $E = h\nu$. In other words, energy (E) is directly proportional to frequency (ν) and so high energies correspond to high frequencies; thus the order would be the same as in question 2.

4. Consider light with a wavelength of 470 nm.

a. What color of visible light would this correspond to?

Blue

b. What would the frequency of this light be?

$$470 \text{ nm} = 4.70 \times 10^{-7} \text{ m}$$

$$\nu = c/\lambda = 3 \times 10^8 \text{ m}\cdot\text{s}^{-1} / 4.70 \times 10^{-7} \text{ m} = 6.38 \times 10^{14} \text{ s}^{-1} = 6.38 \times 10^{14} \text{ Hz}$$

c. How much energy would a single photon of this light possess? Express your answer in joules.

$$E = h\nu = 6.626 \times 10^{-34} \text{ J}\cdot\text{s} \cdot 6.38 \times 10^{14} \text{ s}^{-1} = 4.23 \times 10^{-19} \text{ J}$$

d. How much energy would a mole of such photons possess? Express your answer in kilojoules per mole.

Remember, we just calculated a single photon's energy in joules, so just multiply by Avogadro's number to get joules per mole and then convert to kilojoules per mole. You can think of it like this:

$$4.23 \times 10^{-19} \text{ J}\cdot\text{photon}^{-1} \cdot 6.022 \times 10^{23} \text{ photons}\cdot\text{mol}^{-1} = 254,692 \text{ J}\cdot\text{mol}^{-1} = 250. \text{ kJ}\cdot\text{mol}^{-1}$$

5. If the average bond energy for the O-H bond in water is $458.9 \text{ kJ}\cdot\text{mol}^{-1}$, what is the minimum frequency of light necessary to break that bond?

This is just the reverse of the two calculations done in question 4 parts d and c.

$$458.9 \text{ kJ}\cdot\text{mol}^{-1} / 6.022 \times 10^{23} \text{ photons}\cdot\text{mol}^{-1} = 7.620 \times 10^{-19} \text{ J}\cdot\text{photon}^{-1}$$

$$\nu = E/h = 7.620 \times 10^{-19} \text{ J} / 6.626 \times 10^{-34} \text{ J}\cdot\text{s} = 1.150 \times 10^{15} \text{ s}^{-1} = 1.150 \times 10^{15} \text{ Hz}$$

6. What failed prediction made by classical mechanics about the nature of electromagnetic radiation led to the ultraviolet catastrophe?

Classical mechanics predicted that the power radiated by a blackbody radiator (a fancy name for a hot object that radiates all frequencies of electromagnetic radiation) would be proportional to the square of the frequency at which it emitted radiation, and thus approach infinity as the frequency increased. This was obviously not the case – at higher frequencies (like ultraviolet!), blackbody radiators emit less, not more (let alone infinite) power. This was a catastrophic failure of classical mechanics. Whence, ultraviolet catastrophe.

7. What is the photoelectric effect? How did it demonstrate the inadequacy of the classical mechanical

description of light?

The photoelectric effect was the observation that when light was shined on a metal surface, electrons were ejected from the metal. Classical mechanics predicted that the energy of the ejected electrons would be proportional to the intensity of the light regardless of its frequency. Experimentally, however, it was observed that a minimum frequency (energy) of light was required to eject a photon and that the energy of the ejected photon was proportional to the energy of the incident light, but not the light's intensity. Classical mechanics fail.

8. What is the de Broglie wavelength of a standard round fired from a Mauser C96? A standard round would have a mass of 5.6 g and an initial velocity of 430 m·s⁻¹.

$$5.6 \text{ g} = 5.6 \times 10^{-3} \text{ kg}$$

$$\lambda = h/p = h/(mv) = 6.626 \times 10^{-34} \text{ J}\cdot\text{s} / (5.6 \times 10^{-3} \text{ kg} \cdot 430 \text{ m}\cdot\text{s}^{-1}) = 2.8 \times 10^{-34} \text{ m}$$

9. What would the relativistic (hypothetical) mass of a photon of red (700 nm) light in a vacuum be?

$$700 \text{ nm} = 7.00 \times 10^{-7} \text{ m}$$

$$m = h/(\lambda v) = 6.626 \times 10^{-34} \text{ J}\cdot\text{s} / (7.00 \times 10^{-7} \text{ m} \cdot 3.0 \times 10^8 \text{ m}\cdot\text{s}^{-1}) = 3.16 \times 10^{-36} \text{ kg}$$

10. Using the relativistic mass of the photon calculated above, and the equation $E = mc^2$, calculate the energy of that photon. Compare that value to the value derived using Planck's relation.

$$E = mc^2 = 3.16 \times 10^{-36} \text{ kg} \cdot (3.0 \times 10^8 \text{ m}\cdot\text{s}^{-1})^2 = 2.84 \times 10^{-19} \text{ J}$$

$$E = hv = hc/\lambda = 6.626 \times 10^{-34} \text{ J}\cdot\text{s} \cdot 3.0 \times 10^8 \text{ m}\cdot\text{s}^{-1} / 7.00 \times 10^{-7} \text{ m} = 2.84 \times 10^{-19} \text{ J}$$

The two values should be exactly the same if you didn't round anywhere. You'll notice that since E is one value for a given photon, you can state that $mc^2 = hc/\lambda$, which conveniently rearranges to the de Broglie equation.

11. What is the minimum uncertainty in the position of an electron (mass = 9.11×10^{-31} kg) traveling at a velocity with an uncertainty of 3.0×10^7 m·s⁻¹?

$$\Delta x \Delta p \geq h/4\pi$$

$$\Delta x(m\Delta v) \geq h/4\pi$$

$$\Delta x \geq h/(4\pi m\Delta v)$$

$$\Delta x \geq 6.626 \times 10^{-34} \text{ J}\cdot\text{s} / (4\pi \cdot 9.11 \times 10^{-31} \text{ kg} \cdot 3.0 \times 10^7 \text{ m}\cdot\text{s}^{-1})$$

$$\Delta x \geq 1.93 \times 10^{-12} \text{ m}$$

12. If scientists wanted to calculate the mass of a newly discovered subatomic particle for which they had only position ($\Delta x = 3.313 \times 10^{-9}$ m) and velocity ($\Delta v = 2.0 \times 10^6$ m·s⁻¹) data, what would that mass be. Why is this a bad method to calculate a particle's mass?

$$m \geq h/(4\pi\Delta x\Delta v)$$

$$m \geq 6.626 \times 10^{-34} \text{ J}\cdot\text{s} / (4\pi \cdot 3.313 \times 10^{-9} \text{ m} \cdot 2.0 \times 10^6 \text{ m}\cdot\text{s}^{-1})$$

$$m \geq 7.96 \times 10^{-33} \text{ kg}$$

This is a bad method to calculate mass because the uncertainty principle is an equality, and so this calculation only establishes a lower limit for the mass of the particle, which could potentially be much more massive.

13. From memory (to the best of your ability) list all possible values (the boundary conditions) for the quantum numbers n , l , m_l , m_s .

n , can have any integer value from 1 to infinity **Z**(1, ∞)

l , can have any integer value from 0 to $n-1$ **Z**(0, $n-1$)

m_l , can have any integer value from $+l$ to $-l$ **Z**($+l$, $-l$)

m_s , can have a value of either $+1/2$ or $-1/2$

14. Determine whether the following sets of quantum numbers are valid. If you determine they are invalid, explain your reasoning

a. $n = 3, l = 0, m_l = 0, m_s = +\frac{1}{2}$

Valid.

b. $n = 3, l = 2, m_l = -2, m_s = +1$

Invalid; +1 is not a possible value for m_s .

c. $n = 0, l = 0, m_l = 0, m_s = +\frac{1}{2}$

Invalid; n cannot be zero, it can only have integer values from 1 to infinity.

d. $n = 2, l = 2, m_l = -1, m_s = -\frac{1}{2}$

Invalid; l cannot be equal to n , it can only be less than n .

e. $n = 4, l = 3, m_l = +4, m_s = -\frac{1}{2}$

Invalid; m_l has integer values from $-l$ to $+l$, +4 is greater than +3 and thus invalid.

15. Suggest possible values for quantum numbers that could fill in the blanks below without violating any boundary conditions.

a. $n = 3, l = 0, m_l = \underline{\quad}, m_s = +\frac{1}{2}$

0

Because l is 0, m_l can only be 0.

b. $n = 6, l = \underline{\quad}, m_l = +3, m_s = +\frac{1}{2}$

3, 4 or 5

Because $n = 6$, l could be 0, 1, 2, 3, 4 or 5, but because $m_l = +3$, l must be at least 3.

c. $n = 2, l = 1, m_l = -1, m_s = \underline{\quad}$

$+\frac{1}{2}$ or $-\frac{1}{2}$

Because m_s can only have a value of either $+\frac{1}{2}$ or $-\frac{1}{2}$, it doesn't matter what the other quantum numbers are.

16. State the Aufbau principle in your own words. Without consulting a table, your notes or any peers, write the Aufbau order. (Hint: you can read the Aufbau order right off the periodic table.)

The Aufbau principle states that electrons will fill lower energy orbitals before filling higher energy orbitals.

1s, 2s, 2p, 3s, 3p, 4s, 3d, 4p, etc. Remember, you can read this right off the periodic table. Just apply the fact that p orbitals start at 2p, d orbitals at 3d, and f orbitals at 4f.

17. State Hund's rule in your own words.

In the simplest terms, Hund's rule states that all degenerate orbitals in a given subshell should be half-filled with electrons before any degenerate orbital is completely filled with electrons.

18. State the Pauli exclusion principle in your own words.

Any valid set of 4 quantum numbers can describe one and only one electron in a given atom or ion, likewise each electron is described by one and only unique set of 4 quantum numbers.

19. Using quantum numbers, describe:

a. The highest energy electron in a Boron atom.

$$n = 2, l = 1, m_l = 1, m_s = +\frac{1}{2}$$

b. The lowest energy electron in a Xenon atom.

$$n = 1, l = 0, m_l = 0, m_s = +\frac{1}{2}$$

20. What is an element that can have a ground state electron described by the quantum numbers:

$$n = 7, l = 1, m_l = 1, m_s = +\frac{1}{2}$$

Ununtritium (Uut), or any element beyond it in the periodic table is an acceptable answer.