

## Fall 2009 CH301 Worksheet 1 Answer Key

1. Briefly explain what is meant by "wave-particle duality of light" in your own words.

Light is neither a wave nor a particle but rather something different which exhibits properties of both waves and particles, sometimes called a "waveicle."

2. What equation corresponds to the wave nature of light? Diagram the equation as part of your response. Note: diagramming an equation involves labeling each term with its common name, its Greek name if it is a Greek letter, its units (which may have various names) and finally discussing the proportionality of the various terms in the equation.

The wave nature of light is described by the equation  $c = \lambda \cdot \nu$ , which relates the speed of light ( $c$ , meters per second,  $\text{m} \cdot \text{s}^{-1}$ ) to the wavelength ( $\lambda$ , lambda, meters,  $\text{m}$ ) and the frequency ( $\nu$ , nu, Hertz,  $\text{Hz}$ ,  $\text{s}^{-1}$ ); because the speed of light is a constant in a given medium, wavelength and frequency are inversely proportional.

3. What equation corresponds to the particle nature of light? Diagram the equation as part of your response.

The particle nature of light is described by the equation  $E = h \cdot \nu$ , which relates the energy of a photon ( $E$ , joules,  $\text{J}$ ) to the Planck constant ( $h$ , joule second,  $\text{J} \cdot \text{s}$ ) and the frequency ( $\nu$ , nu, Hertz,  $\text{Hz}$ ,  $\text{s}^{-1}$ ); because the Planck constant is just that, energy and frequency are directly proportional.

4. Using a little algebra, derive an equation that expresses a photon's energy in terms of its wavelength. What proportionality exists between energy and wavelength?

$c = \lambda \cdot \nu$  can be rearranged to  $\nu = c/\lambda$

by substituting for  $\nu = c/\lambda$  into  $E = h \cdot \nu$

we can derive  $E = h \cdot c/\lambda$

The equation shows clearly that energy is inversely proportional to wavelength.

5. Calculate the frequency of light that corresponds to the following wavelengths in a vacuum.

a) 700 nm

$$c = \lambda \cdot \nu$$

$$3.00 \text{ E}8 = 700 \text{ E-}9 \cdot \nu$$

$$\nu = 4.29 \text{ E}14 \text{ Hz}$$

b) 45 pm

$$\nu = 6.67 \text{ E}18 \text{ s}^{-1}$$

c) 12 km

$$\nu = 2.50 \text{ E}4 \text{ Hertz}$$

d) 367 Å

$$\nu = 8.17 \text{ E}15 \text{ s}^{-1}$$

6. How would doubling the frequency of a given photon affect the following values?

a)  $E$  it would be doubled

b)  $\lambda$  it would be halved

c)  $c$  no change

d)  $h$  no change

7. Calculate the energy of photons of the following types

a) 350 nm

$$E = h \cdot c/\lambda$$

$$E = 6.63 \text{ E-}34 \cdot 3.00 \text{ E}8 / 350 \text{ E-}9$$

$$E = 5.68 \text{ E-}19 \text{ J}$$

b) 423 GHz

$$E = h \cdot \nu$$

$$E = 6.63 \text{ E-}34 \cdot 423 \text{ E}9$$

$$E = 2.80 \times 10^{-22} \text{ J}$$

c) 12 cm

$$E = 1.66 \times 10^{-24} \text{ J}$$

d) 1.15 EHz

$$E = 7.62 \times 10^{-16} \text{ J}$$

8. Order the following types of light from most to least energetic:  $10^6$  Hz,  $10^6$  m,  $10^{-6}$  m,  $10^{22}$  Hz,  $10^{-10}$  m (Hint: this can be done with zero calculations.)

$$10^{22} \text{ Hz}, 10^{-10} \text{ m}, 10^{-6} \text{ m}, 10^6 \text{ Hz}, 10^6 \text{ m}$$

9. From memory, to the best of your ability, reproduce the electromagnetic spectrum, starting from the most energetic types of electromagnetic radiation:

$\gamma$  rays X rays UV Visible (VIBGYOR) IR microwave radio TV

10. What did Louis de Broglie propose about matter?

Louis de Broglie proposed that matter, including macroscopic particles such as people, have a wavelength.

11. What equation describes his proposition? Diagram the equation.

The equation that describes this de Broglie wavelength is  $\lambda = h/(m \cdot v)$ . It relates wavelength ( $\lambda$ , lambda, meters, m) to the Planck constant (h, joule second, J·s) and an object's momentum, which is the product of its mass (m, kilograms, kg) and its velocity (v,  $\text{m} \cdot \text{s}^{-1}$ ). Because h is very small, a highly massive or fast moving object will have a tiny de Broglie wavelength, which is inversely proportional to an object's momentum.

12. What is wavelength of a lazy neutron ( $m = 1.67 \times 10^{-27}$  kg) traveling at the speed of light through a vacuum ( $3.00 \times 10^8 \text{ m} \cdot \text{s}^{-1}$ )?

$$\lambda = h/(m \cdot v)$$

$$\lambda = 6.63 \times 10^{-34} / (1.67 \times 10^{-27} \cdot 3.00 \times 10^8)$$

$$\lambda = 1.32 \times 10^{-15} \text{ m}$$

13. In your own words, what is Heisenberg's uncertainty principle?

Heisenberg's uncertainty principle states that the position and momentum of a particle can never be known exactly or simultaneously - there is a minimum amount of error (uncertainty) in any measurement of those two properties of a particle.

14. What equation describes Heisenberg's uncertainty principle? Diagram the equation.

Heisenberg's uncertainty principle is described by the equation  $\Delta x \cdot \Delta p \geq \hbar/2$ , which states that the uncertainty in the position ( $\Delta x$ , meters, m) times the uncertainty in the linear momentum ( $\Delta p$ ,  $\text{kg} \cdot \text{m} \cdot \text{s}^{-1}$ ) is at least equal to the reduced Planck constant ( $\hbar = h/2\pi$ , joule second, J·s) over two.

15. Classical mechanics made what prediction about the power emitted by black body radiators at short wavelengths? What was observed experimentally and what was this observation called?

Classical mechanics predicted that black body radiators would emit infinitely increasing power at lower and lower frequencies, which was found not to be the case. This failure of classical mechanics was termed the ultraviolet catastrophe.

16. Define the term "photoelectric effect" in your own words. How did the photoelectric effect impact classical and quantum mechanics?

The photoelectric effect is the observation that sufficiently energetic photons can eject an electron from a metal surface (or anything else for that matter). It was another failing of classical mechanics (specifically wave

theory), which predicted that sufficiently intense light of any energy could eject electrons from any surface.

17. Define the term "degenerate" in your own words in the context of quantum theory.

When discussing a system's energy, two or more configurations with the same energy are said to be degenerate. In short, degenerate means energetically equivalent.

18. Calculate the energy (E) of a neutron in a 1-dimensional "box" of length (L) 200 nm at principle energy level (n) 2. What is the proportionality of E to n for the 1-dimensional box?

$$E = (n^2 \cdot h^2) / (8 \cdot m \cdot L^2)$$

$$E = (2^2 \cdot 6.63 \cdot 10^{-34}^2) / (8 \cdot 1.67 \cdot 10^{-27} \cdot 2.00 \cdot 10^{-7}^2)$$

$$E = 3.29 \cdot 10^{-27} \text{ J}$$

Energy of the particle in a box is directly proportional to the square of the principle energy number.

19. What is the wavelength of an electron in a 100 nm "box" based on the values of the principle quantum number (n) below?

a)  $n = 3$

$$\lambda = 2 \cdot L / n$$

$$\lambda = 2 \cdot 100 / 3$$

$$\lambda = 66.67 \text{ nm}$$

b)  $n = 1$

$$\lambda = 200 \text{ nm}$$

c)  $n = 8$

$$\lambda = 25 \text{ nm}$$

d)  $n = 5$

$$\lambda = 40 \text{ nm}$$

20. What is the term for a point in a box at which there is zero probability of finding the particle? How many such points are there in a box where  $n=4$ .

A region of zero probability is called a "node." The number of nodes in an  $n=4$  box would be 3.