CHEM 103
R&R 11
14 June 2024
Adapted from a 21 June 2021 document

1. Exposure to high doses of microwaves can cause tissue damage. Estimate how many photons, with $\lambda = 12$ cm, must be absorbed to raise the temperature of your eye by 3.5 °C. Assume the mass of an eye is 11 g, with a specific heat capacity of 4.0 J/(g·°C).

$$n \cdot \frac{hc}{\lambda} = q = m c_p \Delta T$$

$$n = \frac{m c_p \Delta T \cdot \lambda}{hc} = \frac{(11 g)(4.0 \frac{J}{g \cdot °C})(3.5 °C) \cdot (0.12 m)}{(6.626 \times 10^{-34} J \cdot s)(3.00 \times 10^8 \frac{m}{s})}$$

$$n = 9.3 \times 10^{25} \text{ photons}$$

2. Molybdenum metal must absorb radiation with a minimum frequency of 1.09×10^{15} s^{-1} before it can eject an electron from its surface via the photoelectric effect.

a. What is the minimum energy needed to eject an electron?

$$E = h\nu = (6.626 \times 10^{-34} J \cdot s)(1.09 \times 10^{15} s^{-1}) = 7.22 \times 10^{-19} J$$

b. What wavelength of radiation will provide a photon of this energy?

$$\lambda = \frac{c}{\nu} = \frac{3.00 \times 10^8 m/s}{1.09 \times 10^{15} s^{-1}} = 2.75 \times 10^{-7} m$$

3. A diode laser emits light at a wavelength of 987 nm. All of its output energy is absorbed in a detector that measures a total energy of 0.52 J over a period of 32 seconds. How many photons per second are being emitted by the laser?

$E_{photon} = \frac{hc}{\lambda}$. Let f = # photons emitted per second

$$\frac{0.52 J}{32 s} = f E_{photon} = f \frac{hc}{\lambda}$$

$$f = \frac{0.52 J}{32 s} \cdot \frac{987 \times 10^{-9} m}{(6.626 \times 10^{-34} J \cdot s)(3.00 \times 10^8 \frac{m}{s})} = 8.1 \times 10^{16} \text{ photons per second}$$

4. Suppose a microwave emits electromagnetic radiation with a wavelength of 11.2 cm. How many photons of radiation are required to heat 200. mL of coffee from 23 °C to 60 °C? If the power of the microwave is 900. W (one watt is one joule per second), how long would it take to heat the coffee? Assume that the specific heat and density of coffee are the same as water's.

$$n\frac{hc}{\lambda} = q = mc_p\Delta T$$

$$\Rightarrow n = \frac{mc_p\Delta T \cdot \lambda}{hc} = \frac{(200.\,g)(4.184\ J\,g^{-1}\,°C^{-1})(37\,°C)(0.112\ m)}{(6.626\times10^{-34}\ J\cdot s)(3.00\times10^{8}\ \frac{m}{s})} = 1.74\times10^{28}$$

$$t = \frac{E}{P} = \frac{(200.\,g)(4.184\ J\,g^{-1}\,°C^{-1})(37\,°C)}{900\ J\cdot s^{-1}} = 34.4\ s$$

(E ← energy; P ← power)

5. What is the maximum number of orbitals (m_l) with:

a. n = 4 and l = 1 $m_l = -1, 0, 1 \Rightarrow 3$
b. n = 2 and l = 2 0. l must be $\leq n-1$
c. n = 3 and l = 2 3d orbitals $\Rightarrow 5$
d. n = 5, l = 2, and m_l = -1 this specifies a single orbital. 1.

6. What are the quantum numbers (n, l, and m_l) that can describe a 3p orbital?

$n=3,\ l=1,\ m_l = -1, 0, +1$

7. What are the quantum numbers that can describe a 5d orbital?

$n=5,\ l=2,\ m_l = -2, -1, 0, +1, +2$

8. What is the maximum number of electrons that can occupy each of the following subshells? (Hint: the Pauli Exclusion Principle states that each electron must have a unique set of quantum numbers.)

a. 3p 6. $n=3,\ l=1,\ m_l \in \{-1, 0, +1\},\ m_s \in \{-\frac{1}{2}, +\frac{1}{2}\}$
b. 2s 2. $n=2,\ l=0,\ m_l = 0,\ m_s \in \{-\frac{1}{2}, +\frac{1}{2}\}$
c. 5d 10. $n=5,\ l=2,\ m_l \in \{-2, -1, 0, +1, +2\},\ m_s \in \{-\frac{1}{2}, +\frac{1}{2}\}$
d. 4f 14. $n=4,\ l=3,\ m_l \in \{-3, -2, -1, 0, +1, +2, +3\},\ m_s \in \{-\frac{1}{2}, +\frac{1}{2}\}$
e. 3d 10. $n=3,\ l=2,\ m_l \in \{-2, -1, 0, +1, +2\},\ m_s \in \{-\frac{1}{2}, +\frac{1}{2}\}$