CHEM 3523 001 Fall 2023

Name: KEY
ID:

Midterm Exam #2

Answer Sheet: (The conceptual questions are multiple choice. List the letter that corresponds to the correct answer. For the calculation problems list under ***a) the final equation*** that gives the solution. Use only symbols, not intermediate numerical results. List under ***b) the final numerical result***. Make no mistakes when transferring the answers! Put your names on **both** answer sheets **and** the work pages, and **return all pages**! Conceptual questions are **0.5 pts** each, calculation problems **3+1 pts**. Maximum number of points you can get is **25 pts**!

General Infos:

- No programable calculators, smartphones, smartwatches, tablets, headphones, ... are allowed. Neither any notes or books.
- Any attempt of cheating or other forms of academic dishonesty will result in an automatic "F" for the course.
- **Show a picture ID** when leaving
- **Be considerate if you finish early**. Consider to stay till end, or at least be quite when leaving earlier to avoid distracting your fellow students!

Conceptual questions:

1) B
2) A
3) B
4) B
5) C
6) C
7) A
8) B
9) B
10) B

Problems & Calculations:

1a) $\lambda \propto 1/\mu$ $\lambda(D) = \lambda(H)\frac{\mu_H}{\mu_D}$

1b) 404 nm

2a) $n = \sqrt{8 E m_e} \cdot \frac{L}{h}$

2b) $n = 6$

3a) $W + E_{kin} = \frac{hc}{\lambda} \Rightarrow \lambda_{max} = \frac{hc}{W}$

3b) 279 nm

4a) $\Delta E(J \to J+1) = \frac{\hbar^2}{I}(J+1)$, $\Delta E \propto \frac{1}{\lambda}$, $\lambda(4\to5) = \frac{2}{5}\lambda(1\to2)$

4b) 240 nm

5a) $A = \log_{10}\frac{I_0}{I}$ $c = \frac{A}{\varepsilon l}$

5b) 3.9 g/dm³

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Conceptual Questions:

1. Which of the following pairs of quantities can be measured together with arbitrary precision?
   a. z and p_z
   (b.) x and p_z
   c. x and p_x
   d. none of a) – c)

2. A one-dimensional system is described by a Hamilton operator $\hat{H} = -h^2/(8\pi^2 m)\, d^2/dx^2 + V(x,t)$. Can the mechanics of this system described in principle by a *time-independent* Schrödinger equation $\hat{H}\,\Psi(x) = E\Psi(x)$?
   (a.) No
   b. Yes
   c. Maybe

3. In quantum mechanics, measurable quantities are described by linear hermitian operators. Is it true that the spectrum of eigenvalues of such an operator corresponds to the set of all *possible* measurements?
   a. False
   (b.) True

4. For a particle in a one-dimensional box, the energy gap between adjacent energy levels
   a. Increases with increasing size of the box
   (b.) Decreases with increasing size of the box
   c. Is independent from size of the box

5. With increasing quantum numbers the difference between energy states in a harmonic oscillator
   a. Decreases
   b. Increases
   (c.) Stays constant
   d. oscillates

6. The De Broglie wavelength of particles traveling with a certain velocity
   a. Does not depend on its mass
   b. Increases with increasing mass
   (c.) Decreases with increasing mass

7. Compared to that of infrared light, is the momentum of photons of ultraviolet light
    a. Higher
    b. Lower
    c. Is the same.

8. Fermions are particles with
    a. No spin
    b. Half-integer spin
    c. Integer spin

9. For a Helium atom in the ground state, the two electrons
    a. do not have a spin
    b. have opposite spins
    c. have the same spin

10. The absorbance A of a solution depends on the concentration of the solute
    a. False
    b. True

Problems and Calculations:

1. The Brackett spectrum of hydrogen (transitions into n=4) has a line of wavelength of 4050 nm. What is the wavelength (in nm) of the corresponding line of deuterium? ($m_H = 1.6727 \times 10^{-27} kg, m_D = 3.3434 \times 10^{-27} kg$)

$$\mu_H = \frac{m_e \cdot m_H}{m_e + m_H} = 9.104 \times 10^{-31} kg$$

$$\mu_D = \frac{m_e \cdot m_D}{m_e + m_D} = 9.107 \times 10^{-31} kg$$

$$\frac{1}{\lambda} = \frac{Z e^2}{8 \pi \varepsilon_0 h a_0} \left(\frac{1}{n} - \frac{1}{4^2} \right); \quad a_0 = \frac{h \varepsilon_0}{\pi e^2 \mu}$$

$$\lambda \propto \frac{1}{\mu}$$

$$\Rightarrow \frac{\lambda(D)}{\lambda(H)} = \frac{\mu_H}{\mu_D}$$

$$\Rightarrow \lambda(D) = \lambda(H) \cdot \frac{\mu_H}{\mu_D}$$

$$= 4050 nm \cdot \frac{9.104}{9.107}$$

$$= 4048.7 \ nm$$

2. An electron is confined to a one-dimensional box 1.25 nm long. How many energy levels are there with energy less than 1.5 x 10^{-18} J?

$$E_n = \frac{n^2 h^2}{8 m_e l^2} < E \qquad E = 1.5 \times 10^{-18}\ \text{J}$$

$$l = 1.25\ \text{nm}$$

$$\Rightarrow n^2 < E \cdot \frac{8 m_e l^2}{h^2}$$

$$\Rightarrow n < \sqrt{8 \cdot E \cdot m_e}\ \frac{l}{h} = \sqrt{8 \cdot 1.5 \times 10^{-18} \cdot 9.109 \cdot 10^{-31}} \cdot \frac{1.25 \times 10^{-9}}{6.626 \times 10^{-34}}$$

$$= \sqrt{1.0931 \times 10^{-47}} \cdot 1.887 \times 10^{+24}$$

$$= 3.306 \times 10^{-24} \cdot 1.887 \times 10^{+24}$$

$$= 6.24$$

$$\Rightarrow n = 6$$

3. When a photon with the wavelength of 200 nm hits a certain metal, it can eject an electron with a kinetic energy of 2.8×10^{-19}J. What would be the largest wave length with that a photon could still eject an electron?

$$h\nu = E_{Kin} + W \Rightarrow W = h\nu - E_{Kin} = \frac{hc}{\lambda} - E_{Kin}$$

$$\left.\begin{aligned} h\nu_{Min} &= W \\ &= h\frac{c}{\lambda_{max}} \end{aligned}\right\} \Rightarrow \lambda_{max} = \frac{hc}{W}$$

$$= \frac{hc}{\frac{hc}{\lambda} - E_{Kin}}$$

$$= \frac{6.626 \times 10^{-34} \cdot 2.998 \times 10^{8}}{\frac{hc}{200 \times 10^{-9}} - 2.8 \times 10^{-19}} \text{ m}$$

$$= \frac{1.9798 \times 10^{-25}}{\frac{1.9798 \times 10^{-25}}{200 \times 10^{-9}} - 2.8 \times 10^{-19}} \text{ m}$$

$$= \frac{1.9798 \times 10^{-25}}{9.899 \times 10^{-19} - 2.8 \times 10^{-19}} \text{ m}$$

$$= \frac{1.9798 \times 10^{-25}}{7.099 \times 10^{-19}} \text{ m}$$

$$= 2.789 \times 10^{-7} \text{ m}$$

$$= 279 \text{ nm}$$

4. A diatomic molecule HCl undergoing a rotational transition from J=1 to J=2 in the gas phase emits light with a wavelength of 600nm. Hydrogen has an atomic mass of 1 and Chloride one of 35. What is the wavelength for a transition from J=4 to J=5?

$$\Delta E_{J \to J+1} = \frac{\hbar^2}{I}(J+1) \Rightarrow \Delta E_{4 \to 5} = \frac{\hbar^2}{I} 5$$

$$\Delta E_{1 \to 2} = \frac{\hbar^2}{I} 2$$

$$\Delta E_{4 \to 5} = \frac{5}{2} \Delta E_{1 \to 2}$$

$$\Delta E \propto \frac{1}{\lambda} \Rightarrow \lambda(4 \to 5) = \frac{2}{5} \lambda(1 \to 2) = 240 \text{ nm}$$

5. The molar absorption coefficient of human hemoglobin (molecular weight 64,000) is 532 $dm^3/(cm*mol)$ at 440 nm. A solution of hemoglobin in a cuvette having a light path of 3.5 cm was found at that wavelength to have a transmittance of 55%. Calculate the concentration in g/dm^3.

$$A = \varepsilon \cdot c \cdot l \qquad A = \log_{10} \frac{1}{T} = -\log_{10} T = -\log_{10} 0.55$$

$$= 0.2596$$

$$\Rightarrow c = \frac{A}{\varepsilon \cdot l} = \frac{0.2596}{532 \frac{dm^3}{cm \cdot mol} \cdot 3.5 cm}$$

$$= 1.394 \times 10^{-4} \frac{mol}{dm^3}$$

$$= 1.394 \times 10^{-4} \frac{mol}{dm^3} \cdot 6.023 \times 10^{23} \frac{1}{mol} \cdot 6.4 \times 10^{4} \cdot 1.661 \times 10^{-27} kg$$

$$= 8.925 \times 10^{-3} \, kg/dm^3$$

$$= 8.9 \frac{g}{dm^3}$$