CHEM 3523 001 Fall 2026 **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:	Problems & Calculations:
1) B	
2) B	1a) wavelength of cat too small to be measured
3) B	1b) _____
4) C	
5) B	2a) $E_{ph} = h\frac{c}{\lambda}$, $n_{photon} = \frac{P \cdot t}{E_{photon}}$
6) A	2b) 1.69×10^{20}
7) A	
8) A	3a) $\frac{1}{\lambda} = R_H\left(\frac{1}{1^2} - \frac{1}{4^2}\right)$
9) d	3b) _____ 97.25 nm
10) A	
	4a) $\nu = J(J+1)B$, $B = \frac{\Delta\nu}{2}$, $B = \frac{h}{8\pi^2 I}$, $I = \mu r^2$
	4b) 0.11 nm
	5a) $\nu_0 = c/\lambda$, $E = (n+\frac{1}{2})h\nu_0$
	5b) _____
	$E = 2.11 \times 10^{-19}$ J

CHEM 3523 001 Spring 202 6 **Name:**
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Conceptual Questions:

1. What is the ground-state energy of the harmonic oscillator?
   a. $E_0 = 0$
   b. $E_0 = \frac{1}{2} h\nu$
   c. $E_0 = h\nu$
   d. $E_0 = 3/2\ h\nu$
   e. $E_0 = 2\ h\nu$
   f. none of a) - e)

2. The mechanics of a given system is described by a time-independent Schrödinger equation. The probability density of finding a particle at a certain location is then proportional to
   a. The wave function $\Psi(x)$
   b. $|\Psi(x)|^2$
   c. cannot be determined.

3. The De Broglie wavelength of a particle traveling with a certain velocity
   a. Increases with increasing mass
   b. Decreases with increasing mass
   c. Is independent from its mass

4. Which of the following pairs of quantities can be measured together with arbitrary precision?
   a. x and p_x
   b. y and p_y
   c. x and p_y
   d. none of a) – c)

5. For a particle in a one-dimensional box, the probability to find the particle is always larger than zero at any place within the box.
   a. True
   b. False

6. The momentum of photons of ultraviolet light is compared to that of infrared light
   a. Higher
   b. Lower
   c. Is the same.

7. The Pauli-exclusion principle applies to
   a. Only fermions
   b. Only Bosons
   c. All forms of matter and radiation
   d. Only photons

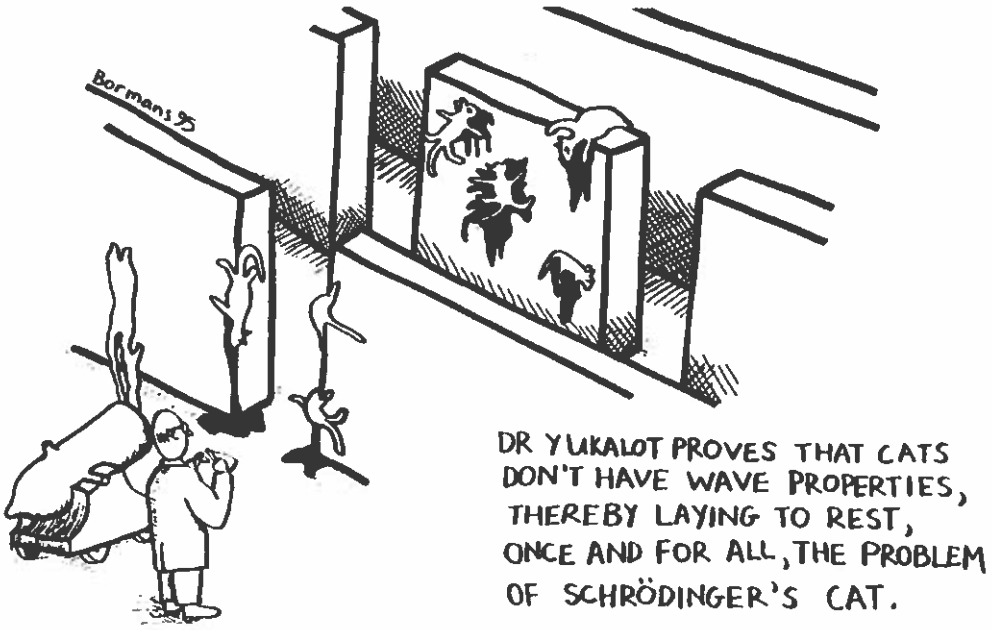
8. In quantum mechanics, measurable quantities are described by linear Hermitian operators. Is it true that the spectrum of eigenvalues of such an operator corresponds to the set of all possible measurements?
   a. True
   b. False

9. Diatomic molecules can be described as linear rotors. In this model, the difference between two energy levels is proportional to
   a. The distance between the two atoms
   b. The square of the distance between the two atoms
   c. The inverse distance between the two atoms
   d. The square of the inverse distance between the two atoms.

10. Which of the four quantum numbers n, l, m_l, and s, describing the state of an electron in the hydrogen atom appears already in the Bohr model of the hydrogen atom?
   a. n
   b. l
   c. m_l
   d. s
   e. none of these four quantities has an equivalent in the Bohr-model

Problems and Calculations:

1. Why does this experiment (to which my cat strongly objects) fail? Assume that cats weight on average 5kg and would fly with about 10km/h.



The wavelength of a cat is too small to be resolved by a macroscopic grating

$$p = 5\,kg \cdot 10\,km/h = 5\,kg \cdot \frac{10000\,m}{3600\,s} = 13.9\,\frac{m}{s}$$

$$\lambda = \frac{h}{p} = \frac{6.626}{13.9} \cdot 10^{-34}\,m = 4.77 \times 10^{-35}\,m$$

2. A 60 W lamp emits light at a wavelength of 560 nm. How many photons does the lamp emit per second?

$$\nu = \frac{c}{\lambda}$$

$$E_{photon} = h\nu = h\frac{c}{\lambda} = \frac{6.626 \times 2.9979 \times 10^{-26}}{560 \times 10^{-9}} J$$

$$= 3.5477 \times 10^{-19} J$$

$$n_{photon} = \frac{Watt \cdot t}{E_{photon}} = \frac{60 J/s \cdot 1 s}{3.5477 \times 10^{-19} J}$$

$$= 1.69 \times 10^{20}$$

3.. **Calculate the wavelength (in nm) corresponding to the n=1 to n=4 transition in the hydrogen atom.**

$$\frac{1}{\lambda} = R_H\left(\frac{1}{1^2} - \frac{1}{4^2}\right) = R_H \frac{15}{16}$$

$$\Rightarrow \lambda = \frac{16}{15 \cdot R_H} = \frac{16}{15 \cdot 1.0968 \times 10^{7}\ /m}$$

$$= 0.9725 \times 10^{-7}\ m$$

$$= 97.25 \times 10^{-9}\ m$$

$$= 97.25\ nm$$

4. In the microwave spectrum of the diatomic molecule $^{12}C^{16}O$ the separation between lines ($\Delta\nu$) has been measured to be 120000 MHz. Calculate the interatomic distance (in nm).

$$\nu = J(J+1)B \Rightarrow \Delta\nu = 2B \Rightarrow B = \frac{\Delta\nu}{2} = 6\times10^{10}\ Hz$$

$$B = \frac{h}{8\pi^2 I} \Rightarrow I = \frac{h}{8\pi^2 B} = \frac{6.626\times10^{-34}}{8\pi^2 \cdot 6\cdot10^{10}} = 1.399\times10^{-46}\ Kg\,m^2$$

$$I = \mu d^2 \Rightarrow d = \sqrt{\frac{I}{\mu}}$$

$$\mu = \frac{12\cdot16}{28}\cdot1.661\times10^{-27}\ Kg = 1.139\times10^{-26}\ Kg$$

$$= \sqrt{\frac{1.399\times10^{-46}}{1.139\times10^{-26}}}$$

$$= \sqrt{1.228\times10^{-20}}\ m$$

$$= 1.11\times10^{-10}\ m$$

$$= 0.11\ nm$$

5. The natural frequency of the N_2 molecule corresponds to a wavenumber of 2360 cm^{-1}. Calculate the energy (in J) corresponding to $\nu = 4$.

$\lambda \cdot \nu = c \Rightarrow \nu = c \cdot \frac{1}{\lambda} \Rightarrow \nu_0 = 2.9979 \times 10^{10} \frac{cm}{s} \cdot 2360 \frac{1}{cm}$

$= 7.075 \times 10^{13} Hz$

$E = (n + \frac{1}{2}) h \nu_0$

$= \frac{9}{2} h \nu_0$

$= 4.5 \times 6.626 \times 10^{-34} \times 7.075 \times 10^{13} J$

$= 2.11 \times 10^{-19} J$