

Chem 6 Sample exam 2 (150 points total)

- @ This is a closed book exam to which the Honor Principle applies.
- @ The last page contains equations and physical constants; you can detach it for easy reference.
- @ Please write clearly and **SHOW YOUR WORK**. If you need to write on the back of the exam paper, please indicate this clearly.
- @ Some questions are more challenging than others. Allot your time accordingly, and try to answer **EVERY** question.
- @ Please put your name both on this page and on page 2.

NAME: _____

NAME: _____

FOR GRADING USE ONLY

Question 1 (12 pts)....._____

Question 2 (15 pts)....._____

Question 3 (16 pts)....._____

Question 4 (16 pts)....._____

Question 5 (12 pts)....._____

Question 6 (12 pts)_____

Question 7 (15 pts)_____

Question 8 (12 pts)_____

Question 9 (12 pts)_____

Question 10 (28 pts)_____

TOTAL (150 pts).....=====

1. (12 pts, 6 each) Hydrogen atoms are the overwhelming majority of atoms in most stars and in interstellar space. In the Carina nebula, transitions due to H atoms in extremely excited states are observed. For example, the $n = 253 \rightarrow n = 252$ transition has been studied by astronomers.

a. (8 pts) **Find the frequency of the photon emitted in this transition.** Be sure to include appropriate units.

b. (4 pts) At least one article suggests that the H atom involved in this transition is big enough to be seen by the unaided eye (if you were spacewalking right next to it in this nebula).

Find the radius of the H atom in the $n = 253$ state. Be sure to include appropriate units.

Could you see this atom, or is that just exaggeration?

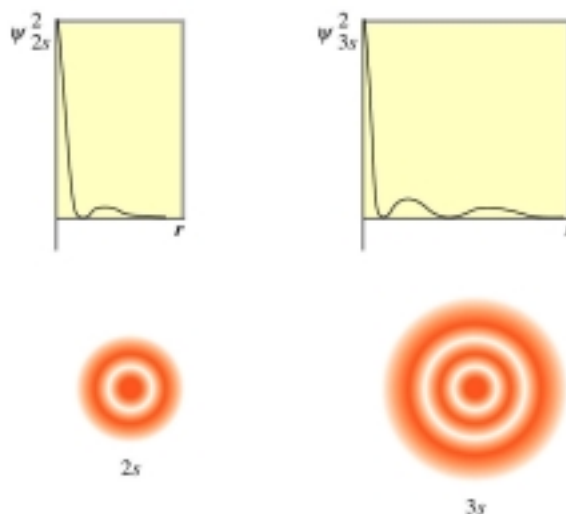
2. (15 pts). Consider an electron in a C=C double bond, which we can model as a 1-dimensional box of length 1.34 \AA . Find the wavelength of light (please include appropriate units) necessary to excite the electron from its ground state to the first excited state.

3. (16 pts) Consider the zero-point energy (ZPE) of two different electrons. One is in a H atom, and the other is in a one-dimensional box. Find the length of the box (L ; include appropriate units) so that the magnitude of the ZPE for its electron is equal to the magnitude of the ZPE for the electron in the H atom:

$$\left| \text{ZPE (box)} \right| = \left| \text{ZPE (atom)} \right|$$

Explain your answer.

4. (16 pts) Here are two different representations of the hydrogen 2s and 3s orbitals, showing the square of the wavefunction and "slices" of the three-dimensional electron density.



(a, 5 pts) What's the physical meaning of the unshaded circles in the lower plots?

(b, 3 pts) On the figure above, draw lines (for both orbitals) to show which points (r values) on the ψ^2 plots correspond to these unshaded circles.

(c, 8 pts) Here are the wavefunctions for these orbitals. C and C' are constants, Z is the atomic number, and $\sigma = Zr/a_0$, where a_0 is the Bohr radius 0.529 \AA . **Find the r values** (for both orbitals) which correspond to the unshaded circles/points in parts a and b above. Explain your answers.

$$\psi_{2s} = C \left(\frac{Z}{a_0}\right)^{\frac{3}{2}} (2 - \sigma) e^{-\frac{\sigma}{2}}$$

$$\psi_{3s} = C' \left(\frac{Z}{a_0}\right)^{\frac{3}{2}} (27 - 18\sigma + 2\sigma^2) e^{-\frac{\sigma}{3}}$$

5. (12 pts, 4 each) **Explain** these experimental observations. (No answers based on the stability of filled shells, please.)

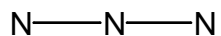
(a) The ionization energies of the alkali metals decrease down the column; similarly, their electron affinities also decrease in magnitude (become less exothermic) as you go down the column.

(b) The atomic radius of B is larger than that of Ne.

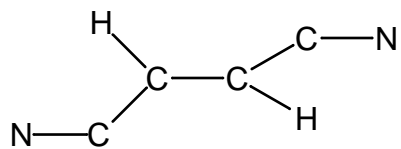
(c) The anion Br^- is larger than Kr.

6. (12 pts, 4 each) Draw acceptable Lewis dot resonance structures *which satisfy the octet rule* for the molecules below. Be sure to include **formal charges** where they are needed. **Circle** the structure you expect to make the greatest contribution to the overall structure (if several structures will make equivalent contributions, circle them all.)

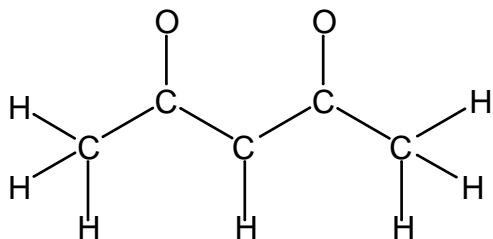
(a) N_3^- (atom connectivity below)



(b) $\text{C}_4\text{H}_2\text{N}_2$ (atom connectivity below)



(c) $\text{C}_5\text{H}_7\text{O}_2^-$ (atom connectivity below)



7. (15 pts, 5 each) Make a sketch to show the expected molecular geometries for these molecules. If any deviations from the idealized bond angles are expected, be sure to include them. If you are artistically challenged, include words to describe your drawing.

(a) XeF_4

(b) BrF_3

(c) I_3^+ (atom connectivity is I-I-I)

8. (12 pts, 6 each). (a) Here are some ionic radii: Ni^{2+} 0.69Å; Pd^{2+} 0.80Å; Pt^{2+} 0.80Å. **Explain** the differences in these radii **qualitatively**.

(b) Explain why the order of orbital energies is $E_{3s} < E_{3p} < E_{4s} < E_{3d}$. First, explain the energy order for the 3s, 3p, and 3d orbitals. Then, explain why $E_{4s} < E_{3d}$.

9. (12 pts) (a, 2 pts) Give the name of the orbital with the quantum numbers $n = 4$, $\ell = 2$.

(b, 2 pts) Give the possible m_ℓ values for this orbital.

(c, 8 pts) Sketch the **angular** part of the wavefunction corresponding to **any one** of these m_ℓ values (you don't need to specify m_ℓ).

Give the **name** of the orbital, clearly label the **axes**, show the number and location of **nodes**, and show, by appropriate shading, the **relative sign** of the wavefunction in different parts of your sketch.

If you are artistically challenged, it may help to describe parts of your picture in words.

10. (28 pts, 4 each) Multiple choice; **circle** your answers, no explanation needed.

(a) Pick the allowed combinations of quantum numbers for an electron in a one-electron atom. There may be more than one correct answer.

(i) $n = 2, \ell = 2, m_\ell = 1, m_s = 1/2$

(ii) $n = 3, \ell = 1, m_\ell = 0, m_s = -1/2$

(iii) $n = 5, \ell = 1, m_\ell = 2, m_s = -1/2$

(iv) $n = 4, \ell = -1, m_\ell = 0, m_s = 1/2$

(b) Pick the **true** statement(s). There may be more than one.

(i) Bohr's atomic model is not applicable to the He atom.

(ii) The probability of finding the electron in a 2p orbital at the nucleus is zero.

(iii) The 5s orbital is not spherical since n is so large.

(iv) The d_{xy} orbital has one angular node.

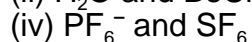
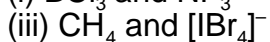
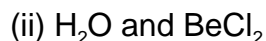
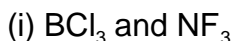
(c) Pick the **false** statement(s) about the particle in a one-dimensional box of length L. There may be more than one.

(i) For the $n = 2$ state, the average position of the particle is at the position $x = L/2$, but the probability of finding the particle at that position is zero.

(ii) Increasing the length of the box leads to shorter wavelengths for the light emitted in transitions between states.

(iii) The probability of finding a particle in a one-dimensional box in level $n = 3$ between the positions $x = 0$ and $x = L/6$ is $1/6$.

(d) Pick the pair(s) of molecules with the **same** molecular geometry. There may be more than one pair.



(e) Pick the true statement(s) about electron affinity.

(i) The **first** electron affinity of gaseous atoms is always negative (exothermic).

(ii) The **second** electron affinity of gaseous atoms is always negative (exothermic).

(iii) The electron affinity of Cl is smaller in magnitude (less exothermic) than that of P.

(iv) The noble gases have low electron affinities.

(f) Put an X in the appropriate boxes to classify the following statements.

Statement #	True for the H atom only	True for all atoms	False for all atoms
i			
ii			
iii			
iv			

(i) The principal quantum number n completely determines the energy of a given electron.

(ii) The angular momentum quantum number, ℓ , determines the shapes of the atomic orbitals.

(iii) The magnetic quantum number, m_ℓ , determines the direction that the atomic orbitals point in space (their orientation).

(iv) the d-orbitals are always degenerate

(g) Pick the true statements. There may be more than one.

(i) For the 1s orbital, the probability of finding the electron 1000.529 \AA from the nucleus is zero.

(ii) An electron can only occupy the positive half of a p-orbital, because electron-electron repulsion is too large in the negatively charged half.

(iii) The maximum radial probability for the H 1s orbital occurs at $r = 0.529 \text{ \AA}$.

(iv) The particle in a one-dimensional box of length L travels from $x = 0$ to $x = L$ by following the curve traced out by the wavefunction ψ .

Equations, etc.

$$m_e = 9.1 \times 10^{-31} \text{ kg}$$

$$1 \text{ nm} = 10^{-9} \text{ m}$$

$$\lambda = h/p$$

$$E = hv$$

$$\hbar = h/2\pi$$

$$e = 1.60 \times 10^{-19} \text{ C}$$

$$(1/2)mv^2 = hv - \phi$$

$$\text{kinetic energy} = (1/2)mv^2 = p^2/2m$$

$$E_n = \frac{-Z^2 e^4 m_e}{8 \epsilon_0^2 n^2 h^2} = -(2.18 \times 10^{-18} \text{ J}) \frac{Z^2}{n^2}$$

$$\Delta E = -2.18 \times 10^{-18} \text{ J Z}^2 (1/n_f^2 - 1/n_i^2)$$

$$v = 3.29 \times 10^{15} \text{ s}^{-1} Z^2 (1/n_f^2 - 1/n_i^2)$$

$$V = (4/3)\pi r^3$$

$$\Psi_n = A \sin\left(\frac{n \pi x}{L}\right)$$

$$\text{Total Energy} = \text{K.E.} + \text{P.E.}$$

$$\text{Quadratic formula: For } ax^2 + bx + c = 0, x = [-b \pm (b^2 - 4ac)^{1/2}]/2a$$

$$N_A = 6.0 \times 10^{23} \text{ atoms/mol}$$

$$1 \text{ \AA} = 10^{-8} \text{ cm} = 10^{-10} \text{ m}$$

$$c = 3 \times 10^8 \text{ ms}^{-1}$$

$$c = v\lambda$$

$$h = 6.626 \times 10^{-34} \text{ Js}$$

$$\Delta x \Delta p \geq \hbar/2$$

$$1 \text{ J} = 1 \text{ kg m}^2 \text{ s}^{-2}$$

$$mvr = nh/2\pi$$

$$a_0 = 0.529 \text{ \AA}$$

$$r_n = (n^2/Z)a_0$$

$$p = mv$$

$$E_n = \frac{n^2 h^2}{8 m L^2}$$

Electronegativity Info

atom	Electronegativity
B	2.04
C	2.55
N	3.04
O	3.44
F	3.98
Cl	3.16

PERIODIC TABLE

¹ H 1.0079																	² He 4.00260
³ Li 6.941	⁴ Be 9.01218											⁵ B 10.81	⁶ C 12.011	⁷ N 14.0067	⁸ O 15.9994	⁹ F 18.9984	¹⁰ Ne 20.179
¹¹ Na 22.9898	¹² Mg 24.305											¹³ Al 26.9815	¹⁴ Si 28.0855	¹⁵ P 30.9738	¹⁶ S 32.06	¹⁷ Cl 35.453	¹⁸ Ar 39.948
¹⁹ K 39.0983	²⁰ Ca 40.08	²¹ Sc 44.9559	²² Ti 47.88	²³ V 50.9415	²⁴ Cr 51.996	²⁵ Mn 54.9380	²⁶ Fe 55.847	²⁷ Co 58.9332	²⁸ Ni 58.69	²⁹ Cu 63.546	³⁰ Zn 65.39	³¹ Ga 69.72	³² Ge 72.59	³³ As 74.9216	³⁴ Se 78.96	³⁵ Br 79.904	³⁶ Kr 83.80
³⁷ Rb 85.4678	³⁸ Sr 87.62	³⁹ Y 88.9059	⁴⁰ Zr 91.224	⁴¹ Nb 92.9064	⁴² Mo 95.94	⁴³ Tc (98)	⁴⁴ Ru 101.07	⁴⁵ Rh 102.906	⁴⁶ Pd 106.42	⁴⁷ Ag 107.868	⁴⁸ Cd 112.41	⁴⁹ In 114.82	⁵⁰ Sn 118.71	⁵¹ Sb 121.75	⁵² Te 127.60	⁵³ I 126.905	⁵⁴ Xe 131.29
⁵⁵ Cs 132.905	⁵⁶ Ba 137.33	⁵⁷ La 138.906	⁷² Hf 178.49	⁷³ Ta 180.948	⁷⁴ W 183.85	⁷⁵ Re 186.207	⁷⁶ Os 190.2	⁷⁷ Ir 192.22	⁷⁸ Pt 195.08	⁷⁹ Au 196.967	⁸⁰ Hg 200.59	⁸¹ Tl 204.383	⁸² Pb 207.2	⁸³ Bi 208.980	⁸⁴ Po (209)	⁸⁵ At (210)	⁸⁶ Rn (222)
⁸⁷ Fr (223)	⁸⁸ Ra 226.025	⁸⁹ Ac 227.028	¹⁰⁴ Unq (261)	¹⁰⁵ Unp (262)	¹⁰⁶ Unh (263)	¹⁰⁷ Uns (262)	¹⁰⁸ Uno (265)	¹⁰⁹ Une (266)									

⁵⁸ Ce 140.12	⁵⁹ Pr 140.908	⁶⁰ Nd 144.24	⁶¹ Pm (145)	⁶² Sm 150.36	⁶³ Eu 151.96	⁶⁴ Gd 157.25	⁶⁵ Tb 158.925	⁶⁶ Dy 162.50	⁶⁷ Ho 164.930	⁶⁸ Er 167.26	⁶⁹ Tm 168.934	⁷⁰ Yb 173.04	⁷¹ Lu 174.967
⁹⁰ Th 232.038	⁹¹ Pa 231.036	⁹² U 238.029	⁹³ Np (237)	⁹⁴ Pu (244)	⁹⁵ Am (243)	⁹⁶ Cm (247)	⁹⁷ Bk (247)	⁹⁸ Cf (251)	⁹⁹ Es (252)	¹⁰⁰ Fm (257)	¹⁰¹ Md (258)	¹⁰² No (259)	¹⁰³ Lr (260)