Chem 1A, Fall 2015, Midterm Exam 1. Version A
September 21, 2015
(Prof. Head-Gordon)²

Name: __________________________________________

Student ID:________________________________________ TA: __________________________

Contents: 9 pages
A. Multiple choice (7 points)
B. Stoichiometry (10 points)
C. Photoelectric effect (8 points)
D. Particle-in-a-box (6 points)
E. Atomic orbitals (6 points)
F. Ionic bonding (6 points)
G. Covalent bonding (10 points)

Total Points: 53 points

Instructions: Closed book exam. Basic scientific calculators are OK. Set brains in high gear and go!

Some possibly useful facts and figures:

\[ R = 8.3145 \text{ J mol}^{-1} \text{ K}^{-1} \] molar volume at STP = 22.4 L
\[ h = 6.6261 \times 10^{-34} \text{ J s} \] \[ h = h/2\pi \]
\[ c = 2.9979 \times 10^{8} \text{ m s}^{-1} \] \[ 1 \text{ eV} = 1.60 \times 10^{-19} \text{ J} \]
\[ m_e = 9.1094 \times 10^{-31} \text{ kg} \]
\[ N_0 = 6.0221 \times 10^{23} \text{ mol}^{-1} \]

Some possibly relevant equations:

Planck relation: \[ E = h\nu \]
de Broglie relation: \[ p = h/\lambda \]
wave equation: \[ c = \nu\lambda \]
uncertainty principle \[ \Delta p \Delta x \geq h/2 \]
particle-in-a-box \[ E_n = \frac{n^2\pi^2h^2}{2ma^2} \]
\[ \Psi_n = \frac{\sqrt{2}}{\sqrt{a}} \sin \frac{n\pi x}{a} \]
hydrogen atom \[ E_n = -\frac{Z^2}{n^2}R_{\infty} \]
\[ R_{\infty} = 2.18 \times 10^{-18} \text{ J} \]
linear momentum \[ p = mv \]
kinetic energy \[ T = \frac{1}{2}mv^2 \]
photoelectric effect \[ E_{\text{kin}} (e-) = h\nu - \Phi = h\nu - h\nu_0 \]
A. Multiple choice (7 points): *there may be one or more correct solutions, so circle all that apply*

1. What is the order of heavy to light of 55 mol of the following substances
   (a) CH$_4$ > CO$_2$ > CO > HF  
   (b) CO$_2$ > CO > HF > CH$_4$
   (c) CH$_4$ > HF > CO > CO$_2$
   (d) HF > CO$_2$ > CO > CH$_4$

2. The following statements are true about the blackbody radiation curve
   (a) As T decreases, the peak moves to longer $\lambda$    
   (b) As T increases, there is an ultraviolet catastrophe
   (c) As T increases, the peak intensity is higher    
   (d) none of the above

3. An electron’s wave-particle duality is captured by
   (a) the Schrodinger equation, $\hat{H}\psi_n(x) = E_n\psi_n(x)$
   (b) Heisenberg uncertainty, $(\Delta p)(\Delta x) \geq h/4\pi$
   (c) the De Broglie relation, $p = h/\lambda$
   (d) all of the above

4. Which transition in Li$^{2+}$ occurs at the same energy as the 4 $\rightarrow$ 2 transition in He$^+$?
   (a) 36 $\rightarrow$ 9
   (b) 16 $\rightarrow$ 1
   (c) 25 $\rightarrow$ 4
   (d) none of the above

5. The wave function for the hydrogen atom
   (a) defines the exact position of the electron
   (b) depends only on the principal quantum number
   (c) always has both radial and angular nodes
   (d) when squared gives the probability density

6. The way(s) in which many-electron atoms differ from one-electron atoms
   (a) s, p, and d sub-shells are no longer degenerate
   (b) nuclear charge seen by e- in outer shell are reduced
   (c) filled shells are stable due to lower screening
   (d) Two paired electrons must occupy each AO

7. The periodic trends for ionization energy of an atom depends on
   (a) Z-number
   (b) Number of e-s between outer e- and nucleus
   (c) electron distance from nucleus
   (d) its electron configuration

------------------------------------------Work Space------------------------------------------
B. (10 points) Stoichiometry and acid etching

(a) (2 points) Hydrofluoric acid, HF, can be used to etch glass by reaction with solid SiO\textsubscript{2} (i.e. glass) to form silicon tetrafluoride (SiF\textsubscript{4}) and water. Write a balanced equation for this reaction.

(b) (2 points) 500 mL of an 0.5M solution of HF is prepared. How many moles of HF does the solution contain?

(c) (3 points) A piece of glass weighing 10.00g is placed in the HF solution. How many moles of Si atoms does the glass sample contain?

(d) (3 points) After waiting long enough for the reaction to complete, predict the mass of SiF\textsubscript{4} produced. Answering this question requires your equation from (a) – skip if you could not do (a).
C. (8 points) **Photoelectric effect and wave-particle duality.** The photoelectric effect involves observing the way in which (i) the number of electrons emitted from a surface, and (ii) their kinetic energy (KE) depends on the radiation directed at the surface. For a particular metal surface, radiation of intensity 1.0 W cm$^{-2}$ and wavelength 300 nm yields electrons of kinetic energy 40 kJ mol$^{-1}$.

(a) (3 points) Predict the effect of increasing the intensity from 1.0 W cm$^{-2}$ to 2.0 W cm$^{-2}$ on the KE of the emitted electrons. (Circle your answer and explain your choice.)

<table>
<thead>
<tr>
<th>KE of e- greater</th>
<th>KE of e- lesser</th>
<th>no difference in KE of e-</th>
</tr>
</thead>
</table>

(b) (3 points) The work function of a material is the energy required to remove an electron. Calculate the work function (eV) of the metal surface used in this experiment.

(c) (2 points) If the experiment is repeated with a new material, and no emitted electrons can be detected with radiation of intensity 1.0 W cm$^{-2}$ and wavelength 300 nm, what can you conclude? (Circle your answer and explain your choice.)

<table>
<thead>
<tr>
<th>Φ metal 1 &gt; Φ metal 2</th>
<th>Φ metal 1 = Φ metal 2</th>
<th>Φ metal 1 &lt; Φ metal 2</th>
</tr>
</thead>
</table>
D. (6 points) Wavefunctions and nodes of the particle in a box. An experiment is performed in which an electron in a confined potential (i.e. like the particle in a box) is promoted from the n=1 energy level to the n=2 energy level with radiation of 400 nm.

(a) (2 points) How many nodes are there in the wavefunction of the n=1 state and the n=2 state of the particle in a box? (Complete the table provided.)

<table>
<thead>
<tr>
<th># nodes</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>n=1</td>
<td></td>
</tr>
<tr>
<td>n=2</td>
<td></td>
</tr>
</tbody>
</table>

(b) (2 points) Predict the effect (on the electron) of changing the wavelength to 300 nm on the experiment giving a reason for your prediction.

(c) (2 points) For the original experiment of 400 nm light, calculate the length of the box.

--Work Space--
E. (6 points) Atomic orbitals and their energy levels.

(a) (2 points) Ionization is the process of removing an electron from an atom or a molecule. Does this process give off energy or require energy? Explain your answer carefully.

(b) (2 points) Calculate the energy change associated with removing a 1s electron from He⁺.

(c) (2 points) Would you expect the ionization energy of the first 1s electron from He to be larger or smaller than the answer you obtained in (b)? (Circle your choice and explain.)

- ionization energy of a 1s in He⁺
- ionization energy of a 1s in He
- > ionization of a 1s in He
- < ionization of a 1s in He

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Work Space--------------------------------------------------
F. (6 points) Ionic bonding

(a) (2 points) A pure substance does not conduct electricity in the solid state but it does dissolve in water and the resulting solution conducts electricity. The substance has a fairly high melting point. Is the substance an ionic compound or a covalent compound? State your reason.

(b) (2 points) Which of the following alkali metals: Na, K, and Rb, will have the shortest critical distance for electron transfer to occur with a fluorine atom, and why?

(c) (2 points) Given the following alkali metal halides: LiCl, KBr, and CsI, what is the order of their lattice energies (energy relative to the isolated ions) from largest to smallest? State the reason for your answer.
G. (10 points) Covalent bonding and Lewis structures.

(a) (4 points) Which of the following Lewis structures are correct (and good) Lewis structures and which are incorrect (or are correct but poor)? Explain what is wrong with the incorrect ones.

<table>
<thead>
<tr>
<th>Structure</th>
<th>OK? (Yes/No)</th>
<th>Correction if no</th>
</tr>
</thead>
<tbody>
<tr>
<td><img src="image1.png" alt="Structure 1" /></td>
<td><img src="image2.png" alt="Yes" /></td>
<td><img src="image3.png" alt="Correction" /></td>
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<td><img src="image9.png" alt="Correction" /></td>
</tr>
</tbody>
</table>

(b) (3 points) The NO₂ molecule is partly responsible for brown color associated with photochemical smog. Draw a Lewis structures for this molecule including all relevant resonance forms and showing any formal charges.

(c) (3 points) Under some conditions of pressure and temperature, two NO₂ molecules can combine to form N₂O₄ molecules. Draw Lewis structures for N₂O₄.