Chem 107 - Hughbanks
Exam 2, March 8, 2012 - Key

Name (Print) ________________________________

UIN # ________________________________

Section 502
Exam 2, Version # A

On the last page of this exam, you’ve been given a periodic table and some physical constants. You’ll probably want to tear that page off the to use during the exam – you don’t need to turn it in with the rest of the exam.
The exam contains 11 problems, with 6 numbered pages. You have the full 75 minutes to complete the exam. **Please show ALL your work as clearly as possible** – this will help us award you partial credit if appropriate. Even correct answers without supporting work may not receive credit. You may use an approved calculator for the exam, one without extensive programmable capabilities or the ability to store alphanumeric information. Print your name above, provide your UIN number, and sign the honor code statement below.

On my honor as an Aggie, I will neither give nor receive unauthorized assistance on this exam.

SIGNATURE: ________________________________
For questions 1 through 4, consider the following gas samples (assume all the gases behave ideally):

A. 40 g of Ar (g) at 0 °C in a 22.4 L container
B. 380 torr of O₂ (g) at 47.6 °C in a 100.0 L container
C. 0.50 mol of H₂ (g) at 47.6 °C in a 5.0 L container

For each question below, please indicate your choice and give a brief justification of your answer (i.e., an explanation of your reasoning). Some numerical calculation is called for, but lengthy calculations can be avoided by use of the proper approach to the problems.

(1) (5 pts) Which gas sample contains the fewest molecules?

Ans. 1 ______ C ______

(2) (5 pts) Which gas sample is at the lowest pressure?

Ans. 2 ______ B ______

(3) (5 pts) The root-mean-square velocity, \( u_{\text{rms}} \), for the hydrogen sample is 2000 m/s. What is \( u_{\text{rms}} \) (in m/s) for the oxygen sample? (Write the numerical answer in the blank space provided.)

Ans. 3 ______ 500 m/s ______

(4) (5 pts) What is the total kinetic energy of the argon gas sample?

Ans. 4 ______ 3405 J ______
(5) (10 points) In (a) – (c), please circle your choices. BE SURE TO READ EACH STATEMENT VERY CAREFULLY!

(a) (3 pts) Which one of the following bonds would be the most polar?

N–H  N–C  N–N  N–S  N–F  N–Br  N–Cl

(b) (4 pts) Which two of the following species would contain 2 unpaired electrons in their ground states?

\[ \text{Mg} \quad \text{C} \quad \text{C}^{2+} \quad \text{Ni}^{2+} \quad \text{Zn}^{2+} \quad \text{Cu}^{2+} \quad \text{N} \]

(c) (3 pts) Which one of the following elements is most likely to form an ion with a –1 charge?

Be  B  C  N  O  F  Ne

(6) (8 points) The figure here shows the structure of methyl salicylate, commonly known as oil of wintergreen.

Put your answers in the spaces provided. BE SURE TO READ EACH STATEMENT VERY CAREFULLY!

(a) (2 pts) What type of hybrid orbitals apply for the carbon atom labeled as “#1”? ___ sp^2___

(b) (2 pts) What type of hybrid orbitals apply for the carbon atom labeled as “#2”? ___ sp^3___

(c) (4 pts) Consider the plane containing carbon atoms #1, #3, and #4 (the “plane of the paper”).

How many atoms in a molecule of methyl salicylate must always lie in that plane? ___12___
Questions 7-11 – show all work (62 pts)

(7) (15 points) In the late 1990s, the Russian space station Mir suffered a failure in its primary oxygen generating system. Similar problems recurred in the international space station in 2004. A backup system for producing oxygen uses so-called “oxygen candles”. In these devices, solid lithium perchlorate (LiClO$_4$) is gently heated and decomposes to give LiCl (an ionic solid) and O$_2$ gas.

(a) (11 pts) Given that the amount of oxygen required each day by a typical adult occupies a volume of 600 L at 293 K and 1 atm pressure, find the mass of LiClO$_4$ that would have to be consumed each day to satisfy the oxygen needs of a 3-person crew aboard Mir.

\[ \text{LiClO}_4(s) \rightarrow \text{LiCl}(s) + 2 \text{O}_2(g) \]

needed O$_2$: \( n(\text{O}_2) = (1.0 \text{ atm})[3(600 \text{ L})]/(0.0821 \text{ L-atm})(293 \text{ K}) = 74.83 \text{ mol} \)

Therefore, we need \( 74.83/2 \text{ mol} = 34.41 \text{ mol of LiClO}_4 \times 106.39 \text{ g/mol} = 3.66 \text{ kg} \)

(b) (4 points) A similar reaction could be carried out using sodium perchlorate (NaClO$_4$) instead of lithium perchlorate, and sodium perchlorate is less expensive. Give a concise explanation for why lithium perchlorate would be a better practical choice for this application.

*It is especially important to choose any option that reduces the mass taken into space. LiClO$_4$ is therefore preferred.*

(8) (10 points) Ammonia is not the only fertilizer in common use. Others include urea, which can be produced by the reaction, CO$_2$(g) + 2 NH$_3$(g) → CO(NH$_2$)$_2$(s) + H$_2$O(g). If 100 g of dry ice are used to provide the carbon dioxide and 6.0 L of ammonia at 20 °C and a pressure of 1.4 atm is added, what is the maximum mass of urea that can be formed?

\[ [100 \text{ g dry ice } (\text{CO}_2(s))]/(42.01 \text{ g/mol}) = 2.38 \text{ mol CO}_2 \]

\[ n(\text{NH}_3(g)) = (1.4 \text{ atm})(6 \text{ L})/(0.0821 \text{ L-atm})(293 \text{ K}) = 0.349 \text{ mol NH}_3 \quad \text{NH}_3 \text{ is limiting} \]

*Can make 0.1746 mol of CO(NH$_2$)$_2$ \( \times 60.62 \text{ g/mol} = 10.49 \text{ g CO(NH}_2)_2 \text{ is the maximum possible*}
The electron binding energies for barium, cesium, lithium, and silver are given in the following table.

<table>
<thead>
<tr>
<th>Metal</th>
<th>Electron Binding Energy (J)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Barium</td>
<td>$4.30 \times 10^{-19}$</td>
</tr>
<tr>
<td>Cesium</td>
<td>$3.11 \times 10^{-19}$</td>
</tr>
<tr>
<td>Lithium</td>
<td>$3.94 \times 10^{-19}$</td>
</tr>
<tr>
<td>Silver</td>
<td>$7.59 \times 10^{-19}$</td>
</tr>
</tbody>
</table>

One way to identify a metal known to be one of these four metals is to perform photoelectric effect experiments. Suppose three experiments were performed using laser light with three wavelengths specified in the table below with the corresponding observations indicating whether photoelectrons were detected (their kinetic energies were not measured). Indicate which of the four metals could have possibly been the “unknown” metal on which these experiments were performed.

<table>
<thead>
<tr>
<th>Laser Wavelength</th>
<th>Photoelectrons Seen?</th>
</tr>
</thead>
<tbody>
<tr>
<td>532 nm</td>
<td>No</td>
</tr>
<tr>
<td>488 nm</td>
<td>Yes</td>
</tr>
<tr>
<td>308 nm</td>
<td>Yes</td>
</tr>
</tbody>
</table>

Clearly show all work in the space below, then circle all the possible metals here:

Barium   Cesium   Lithium   Silver
(10) (10 points) Several excited states of the neon atom are important in the operation of a helium-neon laser. In these excited states, one electron of the neon atom is promoted from the 2p level to a higher energy orbital.

An excited neon atom with a $1s^2 2s^2 2p^5 5s^1$ electron configuration can emit a photon with a wavelength of 3,391 nm as it makes a transition to a lower energy state with a $1s^2 2s^2 2p^5 4p^1$ electron configuration. Other transitions are also possible. If an excited neon atom with a $1s^2 2s^2 2p^5 5s^1$ electron configuration makes a transition to a lower energy state with a $1s^2 2s^2 2p^5 3p^1$ electron configuration, it emits a photon with a wavelength of 632.8 nm. Find the wavelength of the photon that would be emitted in a transition from the $1s^2 2s^2 2p^5 4p^1$ electron configuration to the $1s^2 2s^2 2p^5 3p^1$ electron configuration. (It should help you to draw an energy level diagram.)

\[
\begin{align*}
1s^2 2s^2 2p^5 5s^1 \\
\downarrow \quad \lambda_1 = 3391 \text{ nm}
\end{align*}
\]

\[
\begin{align*}
1s^2 2s^2 2p^5 4p^1 \\
\downarrow \quad \lambda_2 = ? \text{ nm}
\end{align*}
\]

\[
\begin{align*}
1s^2 2s^2 2p^5 3p^1
\end{align*}
\]

Transition from $[5s^1]$ to $[3p^1]$ involves $\lambda_3 = 632.8$ nm.

\[
E_1 + E_2 = E_3 \quad \Rightarrow \quad hc/\lambda_1 + hc/\lambda_2 = hc/\lambda_3 \quad \Rightarrow \quad 1/\lambda_2 = 1/\lambda_3 - 1/\lambda_1 = 1/632.8 - 1/3391 \text{ nm}^{-1}
\]

\[
1/\lambda_2 = 777.9 \text{ nm}
\]
(11) *(15 points)* Below are shown five molecules containing carbon-nitrogen bonds. The diagrams given show only the way the atoms are connected together, they are NOT complete Lewis diagrams. There are five distinct observed C–N bond distances (in pm), in order of increasing length: 115.7, 117.0, 125.7, 133.7, 146.7. Note that only the cyanate ion, [OCN]−, bears a charge – the rest are neutral molecules.

Fill in the table below. Use Lewis diagrams, including any necessary resonance structures, to find the C–N bond orders and decide which observed bond distances belong to which molecules. If you can’t assign an exact value to a bond order, give the best estimate you can by using inequalities (for example, if you think a bond order is greater than 1 but less than 1.5, write $1 < \text{B.O.} < 1.5$.)

<table>
<thead>
<tr>
<th></th>
<th>Bond order</th>
<th>Bond distance*</th>
</tr>
</thead>
<tbody>
<tr>
<td>a</td>
<td>1.5</td>
<td>133.7</td>
</tr>
<tr>
<td>b</td>
<td>1.0</td>
<td>146.7</td>
</tr>
<tr>
<td>c</td>
<td>2.5 &lt; B.O. &lt; 3.0</td>
<td>117.0</td>
</tr>
<tr>
<td>d</td>
<td>3</td>
<td>115.7</td>
</tr>
<tr>
<td>e</td>
<td>2</td>
<td>125.7</td>
</tr>
</tbody>
</table>

*Bond distance choices are (in pm): 115.7, 117.0, 125.7, 133.7, 146.7
<table>
<thead>
<tr>
<th>Name (Print)</th>
<th>Version A</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Actinide Series</strong></td>
<td></td>
</tr>
<tr>
<td>Th</td>
<td>Pa</td>
</tr>
<tr>
<td><strong>Lanthide Series</strong></td>
<td></td>
</tr>
<tr>
<td>Ce</td>
<td>Pr</td>
</tr>
</tbody>
</table>

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**Atomic Molar Mass (Atomic Weight)**

- **H**: 1.00794 g/mol
- **He**: 4.00260 g/mol (exactly)
- **Li**: 6.941 g/mol
- **Be**: 9.0122 g/mol
- **B**: 10.811 g/mol
- **C**: 12.011 g/mol
- **N**: 14.007 g/mol
- **O**: 16.000 g/mol
- **F**: 19.013 g/mol
- **Ne**: 20.180 g/mol

**Pauling Electronegativity**

- **H**: 2.1
- **He**: 1.0

**Physical Constants/Conversion Factors**

- **Speed of light**: $3.00 \times 10^8$ m/s
- **Avogadro's number**: $6.02 \times 10^{23}$
- **Faraday's constant**: $96487$ C mol$^{-1}$ (exact)
- **Electron charge**: $1.60 \times 10^{-19}$ C
- **Fermi's constant**: $9.11 \times 10^{-31}$ kg m$^2$/s$^2$ C$^2$
- **Coulomb constant**: $8.99 \times 10^{9}$ N m$^2$/C$^2$