Instructions: You should have with you several number two pencils, an eraser, your 3" x 5" note card, a calculator, and your University ID Card. If you have notes with you, place them in a sealed backpack and place the backpack OUT OF SIGHT or place the notes directly on the table at the front of the room.

Fill in the front page of the Scantron answer sheet with your class section number (see below), last name, first name, middle initial, and student identification number. Leave the test form number blank.

Section 001 (MWF 8am with Dr. Nafshun)
Section 002 (MWF 11am with Dr. Watson)
Section 003 (MWF 1pm with Dr. Ferguson)
Section 004 (MWF 3pm with Dr. Ferguson)
Section 006 (TR 8am with Dr. Nafshun)

This exam consists of 33 multiple-choice questions; each has 5 points attached. The last question (Question 34) has 3 points attached. When you finish this exam, proceed to the proctor. Submit your completed Scantron form. You may take your notecard and exam packet with you.
\[ \text{PV} = nRT \]

\[ \mu_{\text{rms}} = \sqrt{\frac{3RT}{\text{Molar Mass}}} \]

\[ K = 273.15 + ^\circ C \]

\[ \left( p + \frac{n^2a}{V^2} \right) (V - nb) = nRT \]

<table>
<thead>
<tr>
<th>Number of Electron Groups</th>
<th>Number of Lone Pairs</th>
<th>Electron Pair Geometry</th>
<th>Molecular Geometry</th>
</tr>
</thead>
<tbody>
<tr>
<td>2</td>
<td>0</td>
<td>Linear</td>
<td>Linear</td>
</tr>
<tr>
<td>3</td>
<td>0</td>
<td>Trigonal planar</td>
<td>Trigonal planar</td>
</tr>
<tr>
<td></td>
<td>1</td>
<td>Linear</td>
<td>Bent</td>
</tr>
<tr>
<td>4</td>
<td>0</td>
<td>Tetrahedral (T_d)</td>
<td>Tetrahedral (T_d)</td>
</tr>
<tr>
<td></td>
<td>1</td>
<td>Tetrahedral (T_d)</td>
<td>Trigonal pyramidal</td>
</tr>
<tr>
<td></td>
<td>2</td>
<td>Tetrahedral (T_d)</td>
<td>Bent</td>
</tr>
<tr>
<td>5</td>
<td>0</td>
<td>Trigonal bipyramidal</td>
<td>Trigonal bipyramidal</td>
</tr>
<tr>
<td></td>
<td>1</td>
<td>Trigonal bipyramidal</td>
<td>See-Saw</td>
</tr>
<tr>
<td></td>
<td>2</td>
<td>Trigonal bipyramidal</td>
<td>T-Shaped</td>
</tr>
<tr>
<td></td>
<td>3</td>
<td>Trigonal bipyramidal</td>
<td>Linear</td>
</tr>
<tr>
<td>6</td>
<td>0</td>
<td>Octahedral (O_h)</td>
<td>Octahedral (O_h)</td>
</tr>
<tr>
<td></td>
<td>1</td>
<td>Octahedral (O_h)</td>
<td>Square pyramidal</td>
</tr>
<tr>
<td></td>
<td>2</td>
<td>Octahedral (O_h)</td>
<td>Square planar</td>
</tr>
</tbody>
</table>
Zero-Order

\[
[A]_t = -kt + [A]_0
\]

t_{1/2} = [A]_0/2k

First-Order

\[
\ln [A] = -kt + \ln [A]_0
\]

t_{1/2} = \ln(2)/k = 0.693/k

Second-Order

\[
\frac{1}{[A]} = kt + \frac{1}{[A]_0}
\]

t_{1/2} = 1/(k[A]_0)

\[
\ln k = - \frac{E_a}{RT} + \ln A
\]

1 amu = 1.66054 x 10^{-27} kg = 931.5 MeV

\[
E = mc^2
\]

1 MeV = 1.602 x 10^{-13} J

R = 0.08206 L·atm/mol·K = 8.314 J/mol·K

760 mm Hg = 760 torr = 1 atm

1 m = 1 x 10^{12} pm

1 m = 100 cm

\[
N_A = 6.022 \times 10^{23}
\]

<table>
<thead>
<tr>
<th>Solvent</th>
<th>Normal Freezing Point (°C)</th>
<th>( K_1 ) (°C/m)</th>
<th>Normal Boiling Point (°C)</th>
<th>( K_b ) (°C/m)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Benzene (C₆H₆)</td>
<td>5.5</td>
<td>5.12</td>
<td>80.1</td>
<td>2.53</td>
</tr>
<tr>
<td>Carbon tetrachloride (CCl₄)</td>
<td>-22.9</td>
<td>29.9</td>
<td>76.7</td>
<td>5.03</td>
</tr>
<tr>
<td>Chloroform (CHCl₃)</td>
<td>-63.5</td>
<td>4.70</td>
<td>61.2</td>
<td>3.63</td>
</tr>
<tr>
<td>Ethanol (C₂H₅OH)</td>
<td>-114.1</td>
<td>1.99</td>
<td>78.3</td>
<td>1.22</td>
</tr>
<tr>
<td>Diethyl ether (C₆H₁₄O)</td>
<td>-116.3</td>
<td>1.79</td>
<td>34.6</td>
<td>2.02</td>
</tr>
<tr>
<td>Water (H₂O)</td>
<td>0.00</td>
<td>1.86</td>
<td>100.0</td>
<td>0.512</td>
</tr>
</tbody>
</table>

Abbreviated Solubility Rules:

Rule 1: All nitrates, group 1A metal salts and ammonium salts are soluble.
Rule 2: All carbonates, hydroxides, phosphates and sulfides are insoluble.
Rule 3: I⁻, Cl⁻, Br⁻ are soluble except when combined with Ag⁺ Pb²⁺ Hg²⁺
Rule 4: Rule 1 always takes precedent.

<table>
<thead>
<tr>
<th>Substance</th>
<th>FM (g/mol)</th>
<th>MP (°C)</th>
<th>Heat (f) (J/g)</th>
<th>BP (°C)</th>
<th>Heat (v) (J/g)</th>
<th>Specific Heat (J/g°C)*</th>
</tr>
</thead>
<tbody>
<tr>
<td>acetone</td>
<td>58.1</td>
<td>-95.1</td>
<td>96.7</td>
<td>56.1</td>
<td>520</td>
<td>2.26</td>
</tr>
<tr>
<td>benzene</td>
<td>78.1</td>
<td>5.41</td>
<td>126</td>
<td>80.1</td>
<td>394</td>
<td>1.20</td>
</tr>
<tr>
<td>ethanol</td>
<td>46.1</td>
<td>-112</td>
<td>100</td>
<td>78.3</td>
<td>852</td>
<td>0.96</td>
</tr>
<tr>
<td>n-octane</td>
<td>114</td>
<td>-57.0</td>
<td>182</td>
<td>126</td>
<td>339</td>
<td>1.30</td>
</tr>
<tr>
<td>water</td>
<td>18.0</td>
<td>0.00</td>
<td>334</td>
<td>100</td>
<td>2260</td>
<td>2.09</td>
</tr>
</tbody>
</table>

* Values are estimated based on averages over the temperature range

\[
t_{1/2} \left[^{14}C\right] = 5730 \text{ y}
\]

\[
t_{1/2} \left[^{3}H\right] = 12.3 \text{ y}
\]

\[
t_{1/2} \left[^{238}U\right] = 4.47 \times 10^9 \text{ y}
\]
1. Determine the electron geometry and molecular geometry of NO$_3^-$.

   (A) The electron geometry is trigonal planar; the molecular geometry is trigonal planar.
   (B) The electron geometry is trigonal bipyramidal; the molecular geometry is T-shape.
   (C) The electron geometry is trigonal planar; the molecular geometry is bent.
   (D) The electron geometry is trigonal bipyramidal; the molecular geometry is see-saw.
   (E) The electron geometry is trigonal pyramidal; the molecular geometry is tetrahedral.

2. Which molecule's bonding scheme can be described as sigma bonds formed by the overlap of hydrogen 1s orbitals and carbon sp$^2$ hybridized orbitals, a sigma bond formed by the overlap of carbon sp$^2$ hybridized orbitals, and a pi bond formed by the overlap of carbon unhybridized 2p orbitals?

   (A) C$_2$
   (B) C$_2$H$_2$
   (C) C$_2$H$_4$
   (D) C$_2$H$_6$
   (E) C$_2$H$_8$

3. Under what circumstances will an AB$_n$ molecule have a non-zero dipole moment?

   (A) If the molecule has a tetrahedral molecular geometry.
   (B) If the molecule has a square planar molecular geometry.
   (C) If the molecule has a trigonal bipyramidal molecular geometry.
   (D) If the molecule has a see-saw molecular geometry.
   (E) If the molecule has a linear molecular geometry.
4. Consider molecular orbital theory. Which of the following are paramagnetic?

(A) \( \text{O}_2^{2-} \)
(B) \( \text{Ne}_2 \)
(C) \( \text{O}_2^{2+} \)
(D) \( \text{F}_2^{2-} \)
(E) None of the above are paramagnetic.

5. Molecular orbital theory predicts the \( \text{O}_2^- \) ion has a bond order of:

(A) 0.5
(B) 1.0
(C) 1.5
(D) 2.0
(E) 2.5

6. The \( \text{Cl}-\text{C}-\text{Cl} \) bond angle in \( \text{CCl}_4 \), is:

(A) 180°
(B) 120°
(C) 109.5°
(D) A little greater than 109.5°
(E) A little less than 109.5°
7. A container containing 1 mole of gas, originally at a pressure of \( P_1 \), a volume of \( V_1 \), and at a temperature of \(-173\, ^\circ C\) undergoes two processes. The first occurs at constant temperature with the pressure being doubled. The second takes place at constant pressure with the temperature being raised to \(-73\, ^\circ C\). What is the final volume?

(A) \( 22.4 \, \text{L} \)  
(B) \( V_1 \)  
(C) \( 2V_1 \)  
(D) \( 0.5V_1 \)  
(E) \( 4V_1 \)

8. What pressure will 14.0 g of CO exert in a 3.5 L container at 75°C?

(A) 4.1 atm  
(B) 5.0 atm  
(C) 412 atm  
(D) 1.1 atm  
(E) 0.877 atm

9. A 0.334 g sample of an unknown halogen occupies 109 mL at 398 K and 0.626 atm. What is the identity of the halogen?

(A) \( \text{Br}_2 \)  
(B) \( \text{F}_2 \)  
(C) \( \text{Cl}_2 \)  
(D) \( \text{I}_2 \)  
(E) \( \text{Se} \)
10. Determine the mass of water formed when 12.5 L NH₃ (at 298 K and 1.50 atm) is reacted with excess O₂.

\[ 4 \text{NH}_3(g) + 5 \text{O}_2(g) \rightarrow 4 \text{NO}(g) + 6 \text{H}_2\text{O}(g) \]

(A) 17.0 g H₂O  
(B) 20.7 g H₂O  
(C) 37.7 g H₂O  
(D) 13.8 g H₂O  
(E) 27.9 g H₂O

11. In a container containing CO, H₂, and O₂, what is the mole fraction of CO if the H₂ mole fraction is 0.22 and the O₂ mole fraction is 0.58?

(A) 0.20  
(B) 0.30  
(C) 0.10  
(D) 0.50  
(E) 1.0

12. Which of the following gas samples would be most likely to behave ideally under the stated conditions?

(A) Xe at STP  
(B) CO at 200 atm and 25°C  
(C) SO₂ at 2 atm and 270 K  
(D) N₂ at 1 atm and -70°C  
(E) Ne at STP
13. What is the strongest type of intermolecular force present in NH₂CH₃?

(A) dispersion
(B) dipole-dipole
(C) hydrogen bonding
(D) electronegativity
(E) none of the above

14. Consider CH₃CH₂OH, CaO, CH₃CH₃, CH₃OCH₃, CaS, and Ne. Arranged in increasing melting point, these are:

<table>
<thead>
<tr>
<th>Lowest melting point</th>
<th>Highest melting point</th>
</tr>
</thead>
<tbody>
<tr>
<td>(A) CH₃CH₂OH &lt; Ne &lt; CH₃CH₃ &lt; CH₃OCH₃ &lt; CaO &lt; CaS</td>
<td></td>
</tr>
<tr>
<td>(B) Ne &lt; CH₃CH₃ &lt; CH₃OCH₃ &lt; CH₃CH₂OH &lt; CaO &lt; CaS</td>
<td></td>
</tr>
<tr>
<td>(C) Ne &lt; CH₃OCH₃ &lt; CH₃CH₃ &lt; CH₃CH₂OH &lt; CaS &lt; CaO</td>
<td></td>
</tr>
<tr>
<td>(D) Ne &lt; CH₃CH₃ &lt; CH₃OCH₃ &lt; CH₃CH₂OH &lt; CaS &lt; CaO</td>
<td></td>
</tr>
<tr>
<td>(E) Ne &lt; CH₃CH₃ &lt; CH₃CH₂OH &lt; CH₃OCH₃ &lt; CaO &lt; CaS</td>
<td></td>
</tr>
</tbody>
</table>
15. Similar to your Week 9 Chemistry Laboratory, a pair of students plot \( \ln(k) \) vs. \( 1/T \) data. What is the activation energy for this process?

\[ 15 \]

![Graph of \( \ln(k) \) vs. \( 1/T \)]

(A) 0.0030 kJ/mol  
(B) 3000 kJ/mol  
(C) 73.8 kJ/mol  
(D) 333 kJ/mol  
(E) 24.9 kJ/mol

16. A reaction \( A + B \rightarrow \text{products} \) has the rate law \( \text{rate} = k[A]^2[B] \). Which of the following statements is FALSE?

A) The overall order of reaction is 3.  
B) Increasing \([A]\) by a factor of 2.5, while keeping \([B]\) fixed, will result in an increase in rate by a factor of 5.0  
C) Increasing \([B]\) by a factor of 4.0, while keeping \([A]\) fixed, will result in an increase in rate by a factor of 4.0  
D) Increasing \([A]\) by a factor of 3.0, and increasing \([B]\) by a factor of 2.0, will result in an increase in rate by a factor of 18.0  
E) Decreasing \([A]\) by a factor of 1.5, and increasing \([B]\) by factor of 2.25 will result in no increase in rate.
17. The two diagrams below represent snapshots of a very small portion of a **first-order** reaction in which A molecules are being converted to B molecules (A → B):

![Diagram](image1)

Which of the following diagrams represents a snapshot of a very small portion of this system at t = 3 min?

![Diagram options](image2)
18. The cubic form for the fictitious element JohnCarterium (Jc) is FCC. The atomic radius is 192.0 pm and the molar mass is 306.7 g/mol. The density of Jc is:

(A) 9.16 g/cm³
(B) 10.3 g/cm³
(C) 10.8 g/cm³
(D) 11.4 g/cm³
(E) 12.7 g/cm³

19. Give the net ionic equation for the reaction (if any) that occurs when aqueous solutions of Al(CH₃COO)₃ and LiNO₃ are mixed.

(A) Al³⁺ (aq) + 3 NO₃⁻ (aq) → Al(NO₃)₃ (s)
(B) Li⁺ (aq) CH₃COO⁻ (aq) → LiCH₃COO (s)
(C) Al³⁺ (aq) + 3 NO₃⁻ (aq) + Li⁺(aq) + CH₃COO⁻ (aq) → Al(NO₃)₃ (aq) + Li CH₃COO (s)
(D) 3 Li⁺ (aq) + (CH₃COO)₃⁻ (aq) → Li₃(CH₃COO)₃ (s)
(E) No reaction occurs.
20. How many grams of a polymer with a molar mass of $2.51 \times 10^6$ g/mol must be placed in 900 mL of water at 304 K to produce an osmotic pressure of 0.0441 mm Hg?

(A) $2.09 \times 10^6$ g
(B) 10.8 g
(C) 5.25 g
(D) $4.78 \times 10^6$ g
(E) 7.80 g

21. The boiling point of 1.83 m aqueous KCl (aq) is:

(A) 101.05 °C
(B) 101.02 °C
(C) 102.05 °C
(D) 101.87 °C
(E) 102.09 °C
22. Considering nuclear chemistry, which of the following statements is **false**?

(A) An example of nuclear fusion is $^1_1 \text{H} + ^2_1 \text{H} \rightarrow ^3_2 \text{He}$.
(B) An example of nuclear fission is $^1_0 \text{n} + ^{235}_{92} \text{U} \rightarrow ^{137}_{52} \text{Te} + ^{97}_{40} \text{Zr} + 2 ^1_0 \text{n}$.
(C) The half-life is the time required for the radioactivity of a sample to decay to one-half of its original amount.
(D) The curve of nuclear binding has a maximum near Fe and Ni.
(E) The smaller the nuclear binding energy the more stable the nuclide.

23. A radioactive decay series that begins with $^{232}_{92} \text{U}$ ends with formation of the stable nuclide $^{208}_{82} \text{Bi}$. How many alpha particle emissions and how many beta particle emissions are involved in the sequence of radioactive decays?

(A) 11 alpha and 4 beta decays
(B) 6 alpha and 3 beta decays
(C) 7 alpha and 4 beta decays
(D) 4 alpha and 7 beta decays
(E) 24 alpha and 9 beta decays

24. The number of disintegrations per second of $^{14}_{6} \text{C}$ nuclei in a one-gram sample from a dead tree is 85.3% of that of the disintegrations of a one-gram sample from a living tree. What year did the tree die?

(A) 5730 BC
(B) 2876 BC
(C) 698 AD
(D) 1315 AD
(E) 1716 AD
25. What is the daughter nucleotide of $^{234}$Th when it undergoes beta decay?

(A) Ra-230  
(B) Th-233  
(C) Th-235  
(D) U-238  
(E) Pa-234

26. The mass of the products in the process shown below is:

$$^{235}_{92}U + ^1_0n \rightarrow ^{140}_{56}Ba + ^{93}_{36}Kr + 3^1_0n + \text{energy}$$

\[ \text{Masses: } \begin{align*} &235.04392 \text{ amu} \\ &1.00866 \end{align*} \]

\[ \text{Total: } 236.0528 \text{ amu} \]

(A) 236.0528 amu  
(B) less than 236.0528 amu and releases energy  
(C) greater than 236.0528 amu and releases energy  
(D) less than 236.0528 amu and absorbs energy  
(E) greater than 236.0528 amu and absorbs energy

27. $^{59}$Zn is likely to:

(A) undergo alpha decay  
(B) undergo beta decay  
(C) undergo positron emission  
(D) proton capture  
(E) none of the above
28. A mixture of hydrogen, iodine, and hydrogen iodide, each at 0.0010 M initially, were introduced into a container and heated to 783 K. At this temperature \( K_c = 46 \). To reach equilibrium:

\[
H_2(g) + I_2(g) \leftrightarrow 2HI(g)
\]

(A) The concentration of HI (g) will increase.
(B) The concentration of H\(_2\) (g) will increase.
(C) The concentrations of gases will remain at 0.0010 M.
(D) The concentration of I\(_2\) (g) will decrease.
(E) More information is needed.

29. The equilibrium law expression for the reaction \( 2 \text{NO(g)} + \text{O}_2(g) \rightleftharpoons 2 \text{NO}_2(g) \) is:

(A) \( K_c = \frac{[\text{O}_2][\text{NO}]}{[\text{NO}_2]^2} \)
(B) \( K_c = \frac{[\text{O}_2]^2[\text{NO}]}{[\text{NO}_2]^2} \)
(C) \( K_c = \frac{[\text{NO}_2]^2}{[\text{NO}]^2[\text{O}_2]^2} \)
(D) \( K_c = \frac{[\text{O}_2][\text{NO}]}{[\text{NO}_2]} \)
(E) \( K_c = \frac{[\text{NO}_2]^2}{[\text{NO}]^2[\text{O}_2]} \)
30. A student fills a 0.500-L flask with 0.200 moles of pure NH$_3$ (g) at 298 K. She goes to lunch, returns, and measures the H$_2$ (g) concentration to be 0.112 M. Which statement below is correct?

$$2 \text{NH}_3 (g) \leftrightarrow \text{N}_2 (g) + 3 \text{H}_2 (g) \quad \text{K}_c = 1.71 \times 10^{-6} \text{ at 298 K}$$

(A) The system **has** reached equilibrium and the gas concentrations will remain constant at 298 K.
(B) The system **has** reached equilibrium and more N$_2$ (g) and H$_2$ (g) are expected to form.
(C) The system **has** reached equilibrium and more NH$_3$ (g) is expected to form.
(B) The system **is not** at equilibrium and more N$_2$ (g) and H$_2$ (g) are expected to form.
(C) The system **is not** at equilibrium and more NH$_3$ (g) is expected to form.

31. A student determines K$_c$ to be $5.27 \times 10^{-8}$ for the following system at 973 K:

$$2 \text{H}_2\text{S} (g) + \text{CH}_4 (g) \leftrightarrow 4 \text{H}_2 (g) + \text{CS}_2 (g)$$

What is K$_p$?

(A) K$_p$ = $5.27 \times 10^{-8}$
(B) K$_p$ = $1.90 \times 10^{-7}$
(C) K$_p$ = $8.27 \times 10^{-12}$
(D) K$_p$ = $3.36 \times 10^{-4}$
(E) K$_p$ = $1.90 \times 10^7$
32. The following reaction is at equilibrium:

\[ \text{C (s) + H}_2\text{O (g) } \rightleftharpoons \text{CO (g) + H}_2 \text{ (g)} \quad \Delta H_{\text{reaction}} = +131.3 \text{ kJ} \]

Which of the following is true when heat is added to the system?

(A) The concentration of CO (g) increases 
(B) The concentration of CO (g) decreases 
(C) The concentration of CO (g) stays the same 
(D) The value of K will stay the same.

33. Given the following reactions and their equilibrium constants, calculate the equilibrium constant for the overall reaction 2A + 3B \( \rightarrow \) 4D.

\[
\text{Reaction 1: } A + 3B \rightarrow 2C \quad K_c = 56 \\
\text{Reaction 2: } 4D \rightarrow A + 2C \quad K_c = 21
\]

(A) 1176 
(B) 2.7 
(C) 77 
(D) 35 
(E) 0.38

(Turn Over for Last Question)
Well, well, well... CH 222 is over. Time to...

(A) head home and try to forget about rate constants.
(B) cry; possibly for hours.
(C) two words: Netflix and Skittles.
(D) cut my toe nails.
(E) write my memoirs.

[Any response will receive full credit; even no response.]

Questions 1 through 33 have five points attached (165 total). Any response to Question 34 will receive full credit (3 Points total); even no response. The point total for this exam is 168 points. See the grade sheet for grade computation details. Final exam keys, scores, and course grades will be posted on the CH 222 website as they become available. Have a great and safe term.