There are 20 Multiple choice questions worth 2.5 points each.
• There are 3, multi-part short answer questions.
• For the multiple choice section, fill in the Scantron form AND circle your answer on the exam.
• Put your written answers in the boxes provided. Full credit cannot be gained for answers outside the boxes provided.
• The lecture, homework, chemquizzes, discussion or experiment that each question is based upon is listed after the question e.g. [L3, HW 1.13, CQ 7.3]
• Unless it is specified otherwise, reduce formal charge when drawing structures

<table>
<thead>
<tr>
<th>Question</th>
<th>Points</th>
<th>Score</th>
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<tr>
<td>Multiple Choice Section</td>
<td>50</td>
<td></td>
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<tr>
<td>Question 21</td>
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<tr>
<td>Question 22</td>
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<td>Question 23</td>
<td>13</td>
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<tr>
<td>Total</td>
<td>100</td>
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</tbody>
</table>
**Quantum:**

\[ E = h \nu \]
\[ \lambda_{\text{deBroglie}} = h / p = h / mv \]
\[ E_{\text{kin}} (\text{e-}) = h \nu - \Phi = h \nu - h \nu_0 \]
\[ E_n = \frac{Z^2}{n^2} R_e \]
\[ \Delta x \Delta p \sim h \]
\[ p = mv \]

Particle in a box (1-D Quantum):
\[ E_n = \frac{h^2 n^2}{8 m L^2}; n = 1, 2, 3... \]

Vibrational:
\[ E_v = \left( v + \frac{1}{2} \right) h A / 2 \pi; A = \left( k / m \right)^{1/2} \]

Rotational:
\[ E_n = n(n + 1) h B; B = h / 8 \pi^2 I; I = 2 m r^2 \]
\[ m = m_A m_B / (m_A + m_B) \]

**Ideal Gas:**

\[ PV = nRT \]
\[ E_{\text{kin}} = \frac{3}{2} kT \]
\[ v_{\text{rms}} = \sqrt{\frac{3RT}{M}} \]

**Constants:**

\[ N_0 = 6.02214 \times 10^{23} \text{ mol}^{-1} \]
\[ R_e = 2.179874 \times 10^{-18} \text{ J} \]
\[ R_x = 3.28984 \times 10^{15} \text{ Hz} \]
\[ k = 1.38066 \times 10^{-23} \text{ J K}^{-1} \]
\[ h = 6.62608 \times 10^{-34} \text{ J s} \]
\[ m_e = 9.10939 \times 10^{-31} \text{ kg} \]
\[ c = 2.99792 \times 10^8 \text{ m s}^{-1} \]
\[ T (K) = T (C) + 273.15 \]
\[ F = 96,485 \text{ C / mol} \]
\[ 1 \text{ V} = 1 \text{ J / C} \]

Gas Constant:
\[ R = 8.31451 \text{ J K}^{-1} \text{ mol}^{-1} \]
\[ R = 8.20578 \times 10^{-2} \text{ L atm K}^{-1} \text{ mol}^{-1} \]
\[ 1 \text{ nm} = 10^{-9} \text{ m} \]
\[ 1 \text{ kJ} = 1000 \text{ J} \]
\[ 1 \text{ atm} = 760 \text{ mm Hg} = 760 \text{ torr} \approx 1 \text{ bar} \]
\[ 1 \text{ L atm} \approx 100 \text{ J} \]

**Thermodynamics:**

\[ \Delta G^\circ = \Delta H^\circ - T \Delta S^\circ \]
\[ \Delta H^\circ = \sum \Delta H_f^\circ (\text{products}) - \sum \Delta H_f^\circ (\text{reactants}) \]
\[ \Delta S^\circ = \sum S^\circ (\text{products}) - \sum S^\circ (\text{reactants}) \]
\[ \Delta G^\circ = \sum \Delta G_f^\circ (\text{products}) - \sum \Delta G_f^\circ (\text{reactants}) \]

\[ S = k_B \ln W \]
\[ \Delta S = q_{\text{rev}} / T \]
\[ \Delta E = q + w \]
\[ w = - P_{\text{ext}} \Delta V \]

\[ \Delta T = i k_{b,f} m \]
\[ \Pi = i M R T \]

\[ P_{\text{total}} = P_A + P_B = X_A P_A^\circ + X_B P_B^\circ \]

**Acid Base:**

\[ \text{pH} = - \log [\text{H}_3\text{O}^+] \]

\[ \text{p}X = - \log X \]

\[ \text{pH} = pK_a + \log \left[ \frac{[A^-]}{[HA]} \right] \]

**Kinetics:**

\[ [A]_t = [A]_0 e^{-kt} \]
\[ \ln [A]_t = \ln [A]_0 - kt \]
\[ t_{1/2} = \ln 2 / k \]
\[ 1/[A]_t = 1/[A]_0 + kt \]
\[ k = A e^{(-E_a / R T)} \]
\[ \ln (k_1 / k_2) = E_a / R \left( 1 / T_2 - 1 / T_1 \right) \]
\[ t_{1/2} = 1 / [A]_0 k \]
\[ t_{1/2} = [A]_0 / k t \]
MULTIPLE CHOICE

1) Which of the following has the smallest atomic radius? [HW 1.90]
   A) Al            B) P            C) S            D) Si            E) Cl

2) Which of the following has the largest radius? [HW 1.92]
   A) S^{2-}        B) Cl           C) Cl^{-}       D) K^{+}        E) S

3) Which of the following reactions require energy to occur? [Disc 4]
   A) Na^{+} (g) + e^{-} → Na (g)
   B) F^{+} (g) + e^{-} → F (g)
   C) Both A and B
   D) Neither A nor B

4) Which of the following species have the highest ionization energy? [HW 1.86, CQ11.2]
   A) K^{+}
   B) Ar
   C) Cl^{-}
   D) They have equal ionization energies.

5) Which of the following is the best explanation for your response to the previous question? [L11, Disc 4]
   A) Noble gases are stable. All atoms want noble gas configurations.
   B) The greater the number of protons, the greater the effective nuclear charge.
   C) Removing the second electron from an atom always requires more energy than the first.
   D) They are isoelectronic. All the atoms and ions have the same number of electrons.

6) Consider the following ground-state electronic configurations for neutral atoms. Which atom has both the highest first ionization energy and the highest electron affinity? [HW 1.74, 1.94]
   A) [Ne] 3s^{2}3p^{5}  B) [Ne] 3s^{2}3p^{3}  C) [Ne] 3s^{2}3p^{1}  D) [Ne] 3s^{2}3p^{4}

7) Which of the following metal ions has the ground-state electron configuration [Ar]3d^{6}? [HW 2.8]
   A) Ni^{3+}        B) Fe^{2+}      C) Mn^{2+}      D) Cu^{+}      E) Ca^{2+}
8) For the ground-state ion Pb$^{4+}$, what type of orbital do the electrons with highest energy reside in? [HW 2.24]
   A) 5p       B) 6p       C) 4f       D) 5d       E) 6s

9) All of the following have a linear shape except_________. [CQ 14.3]
   A) CS$_2$     B) CO$_2$     C) I$_3^-$     D) OCS     E) CH$_2^2$-

10) What is the shape of BrO$_4^-$? [HW 3.18]
    A) tetrahedral
    B) trigonal bipyramidal
    C) seesaw
    D) T-shaped
    E) square planar

11) Which of the following is polar? [HW 3.20, 3.26]
    A) N$_2$O     B) XeF$_2$     C) C$_2$H$_6$     D) C$_6$H$_6$     E) CH$_3$OH

12) Arrange the following molecules in order of increasing bond angle. [CQ15.1]
    CCl$_4$, NH$_3$, BF$_2^-$, BH$_3$, H$_2$O
    A) BH$_3$ < BF$_2^-$ < CCl$_4$ < NH$_3$ < H$_2$O
    B) H$_2$O < NH$_3$ < CCl$_4$ < BF$_2^-$ < BH$_3$
    C) CCl$_4$ < BF$_2^-$ < H$_2$O < NH$_3$ < BH$_3$
    D) H$_2$O < BF$_2^-$ < BH$_3$ < NH$_3$ < CCl$_4$
    E) CCl$_4$ < NH$_3$ < BH$_3$ < BF$_2^-$ < H$_2$O

13) A strong trend is seen when comparing the atomic radius of lanthanide elements. This trend is as atomic number increases, the atomic radius______. [HW 1.66]
    A) increases because with the addition of more electrons, there is more electron-electron shielding, causing the electrons to be less tightly bound and further out
    B) decreases because the effective nuclear charge decreases, pulling the electrons more tightly in
    C) decreases because the effective nuclear charge increases, pulling the electrons more tightly in
    D) decreases because with the addition of more electrons, there is less electron-electron shielding, pulling the electrons more tightly in
    E) increases because the effective nuclear charge increases, causing the electrons to be less tightly bound and further out
14) Which of the following statements is true? [L11, HW 1.86, 1.94]
   A) Atoms with low ionization energies and low electron affinities have high
      electronegativities.
   B) Atoms with high ionization energies and high electron affinities have low
      electronegativities.
   C) The electronegativity of an atom depends only on the value of the ionization
      energy of the atom.
   D) Atoms with high ionization energies and high electron affinities are highly
      electronegative.
   E) The electronegativity of an atom is defined as \( \frac{1}{2} \) (Electron Affinity) of the atom.

15) Which of the following molecules is chiral? [CQ 15.4]
   A) Br
   B) Cl Cl
   C) Cl Br
   D) Br Br

16) How many \( \sigma \)- and \( \pi \)-bonds, respectively, are there in acrolein? (shown below) [L17]
   A) 4 and 2
   B) 7 and 2
   C) 5 and 2
   D) 5 and 4
   E) 7 and 1

17) An arrow points to one bond in acrolein. The hybrid
   orbitals used to make the bond, are_____. [CQ 17.4]
   A) \( sp^3 \) (C) and s (H)
   B) \( sp^2 \) (C) and sp (H)
   C) \( sp^2 \) (C) and \( sp^3 \) (H)
   D) \( sp^2 \) (C) and s (H)
   E) sp (C) and \( sp^3 \) (H)
18) What volume is occupied by 1.00 kg of helium at 5.00°C at a pressure of 0.967 atm?
   A) $5.97 \times 10^5$ L
   B) $5.90 \times 10^3$ L
   C) $2.95 \times 10^3$ L
   D) $1.06 \times 10^2$ L
   E) $5.60 \times 10^3$ L

You have two closed 1.0 L containers, one with 1.0 atm of Br$_2$ (g) and the other with 1.0 atm of F$_2$ (g). When the containers are connected and the gases are allowed to mix, Br$_2$ (g) and F$_2$ (g) react to form BrF$_5$ (g). Assume that the reaction goes to completion and that the initial and final temperatures are equal.

\[ \text{Br}_2 \ (g) \ + \ 5 \ F_2 \ (g) \ \rightarrow \ 2 \ \text{BrF}_5 \ (g) \]

19) What is the final pressure in the system after the reaction has taken place?  [CQ18.4]
   A) 1.0 atm
   B) 1.2 atm
   C) 2.0 atm
   D) 0.6 atm
   E) 2.4 atm

20) In lab you performed a titration of the base TRIS with HCl. A student performed four titrations all within 10% error of each other but in each case the final solution was yellow. Which of the following statements are true?
   A) His experiment was both accurate and precise.
   B) His experiment was neither accurate nor precise.
   C) His experiment was accurate but not precise.
   D) His experiment was precise but not accurate.
   E) His experiment will give a falsely high molarity for the HCl solution.
21) **Models of Bonding** (19 points total) [L17, CQ18.1]

Two different models for the bonding in oxygen molecules are shown below. On the left the molecular orbital model is shown; atomic s and p orbitals mix to produce molecular orbitals. On the right the valence bond model is shown; hybrid orbitals mix to produce molecular orbitals.
21) **Models of Bonding** (continued)

a) Using arrows (↓↑) to represent electrons, fill in the atomic and molecular orbitals for O₂ on both diagrams.

b) In the Valence Bond Model, what type of orbital houses the lone pairs of electrons on the oxygen atoms?

c) Experimental data indicates that the bond in oxygen molecules is a double bond. Prove that both models support this evidence.

<table>
<thead>
<tr>
<th>Molecular Orbital Model</th>
<th>Valence Bond Model</th>
</tr>
</thead>
</table>


d) Experimental data indicates that oxygen molecules are attracted to a magnetic field. Which model(s) best supports this data? (Circle all that apply)

<table>
<thead>
<tr>
<th>Molecular Orbital Model</th>
<th>Valence Bond Model</th>
<th>Both Models</th>
</tr>
</thead>
</table>

e) Explain your reasoning.


22) **Evidence for Lewis Structures** (18 points total) [HW1.30, HW 3.34, CQ6.3]

Two xenon compounds that have been synthesized are XeO₃ and XeO₄. Their Lewis dot structures are shown below, respectively:

![Lewis structures of XeO₃ and XeO₄](image)

You are given an unknown sample containing one of these two xenon oxides. For each of the pieces of information below, circle yes if it would allow you to distinguish between XeO₃ and XeO₄. Circle no if it is not sufficient information. Explain your answer in either case.

<table>
<thead>
<tr>
<th>Information</th>
<th>Yes or no?</th>
<th>Briefly explain your reasoning.</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mass spectrum of your Xe compound</td>
<td>yes</td>
<td></td>
</tr>
<tr>
<td></td>
<td>no</td>
<td></td>
</tr>
<tr>
<td>Molecular shape of your Xe compound</td>
<td>yes</td>
<td></td>
</tr>
<tr>
<td></td>
<td>no</td>
<td></td>
</tr>
<tr>
<td>Steric number of Xe in your compound</td>
<td>yes</td>
<td></td>
</tr>
<tr>
<td></td>
<td>no</td>
<td></td>
</tr>
<tr>
<td>Formal charge of Xe in your compound</td>
<td>yes</td>
<td></td>
</tr>
<tr>
<td></td>
<td>no</td>
<td></td>
</tr>
<tr>
<td>O-Xe-O bond angle in your compound</td>
<td>yes</td>
<td></td>
</tr>
<tr>
<td></td>
<td>no</td>
<td></td>
</tr>
<tr>
<td>Bond order of Xe-O bonds in your compound</td>
<td>yes</td>
<td></td>
</tr>
<tr>
<td></td>
<td>no</td>
<td></td>
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</tbody>
</table>
23) **Evidence for Resonance Structures** (13 points total) [HW 1.48, Disc.6]

The thiocyanate ion can be represented by the three resonance structures shown below.

\[
\begin{align*}
\left[ \begin{array}{c}
\vdots \\
\text{S} & \text{C} & \text{N} \end{array} \right]^{-1} & \leftrightarrow \left[ \begin{array}{c}
\vdots \\
\text{S} & \equiv & \text{C} & \equiv & \text{N} \end{array} \right]^{-1} & \leftrightarrow \left[ \begin{array}{c}
\vdots \\
\text{S} & \equiv & \text{C} & \equiv & \text{N} \end{array} \right]^{-1}
\end{align*}
\]

a) Assign formal charge to each of the atoms in the structures shown. Put your answers in the boxes provided.

Examine the experimental data provided below.

<table>
<thead>
<tr>
<th>Bond Type</th>
<th>S-C (pm)</th>
<th>C-N (pm)</th>
</tr>
</thead>
<tbody>
<tr>
<td>single bond</td>
<td>181</td>
<td>147</td>
</tr>
<tr>
<td>double bond</td>
<td>155</td>
<td>128</td>
</tr>
<tr>
<td>triple bond</td>
<td>141</td>
<td>116</td>
</tr>
<tr>
<td>SCN⁻</td>
<td>165</td>
<td>117</td>
</tr>
<tr>
<td>HSCN</td>
<td>156</td>
<td>122</td>
</tr>
</tbody>
</table>

b) Based on the data, which two structures contribute the most to the actual structure of SCN⁻? (Circle the two structures in the molecules above)

c) Explain your reasoning.

The thiocyanate anion can gain H⁺ to become the acid HSCN. The bond lengths for the HSCN molecule are shown in the table.

d) Based on the data, draw the best Lewis structure for the HSCN molecule.