Please answer each of the following questions to the best of your ability. If you wish to receive partial credit, please show your work. For multiple choice, there is no partial credit (unless otherwise noted) and there is only one correct answer (unless otherwise noted). For multiple choice, please clearly mark the correct answer. Good luck!

Relatively new equation (on equation sheet): \( w = -P \Delta V \) \( 1 \text{ L} \cdot \text{atm} = 101.325 \text{ J} \)

Relatively new equation (on equation sheet): \( \nu_{\text{rms}} = \sqrt{\frac{3RT}{MM}} \) \( 1 \text{ inch} = 2.54 \text{ cm} \)

1. Multiple choice are 4 points unless otherwise stated.

1. Which of the following scenarios has the lowest energy?
   A. a hydrogen atom with an electron in the n = 1 principal energy level
   B. a hydrogen atom with an electron in the n = 2 principal energy level
   C. a hydrogen atom with an electron in the n = 3 principal energy level
   D. a hydrogen atom with an electron in the n = 4 principal energy level

2. Which of these could be the values of \( \ell \) and \( m_\ell \) for an electron in a 4p sublevel:
   - A. \( \ell = 0, m_\ell = 0 \)
   - B. \( \ell = 1, m_\ell = 1 \)
   - C. \( \ell = 0, m_\ell = 1 \)
   - D. \( \ell = 2, m_\ell = 2 \)

3. If gas A (molar mass = 32.00 g/mol) and gas B (molar mass = 16.00 g/mol) are in different containers of the same volume at the same temperature and have equal numbers of moles, what is the relationship between their pressures:
   A. \( P_A > P_B \)
   B. \( P_A < P_B \)
   C. \( P_A = P_B \)
   D. There is not enough information to tell the relationship.

4. Using the graph below for which T = 0°C, determine the gas that has the lowest molar mass.

![Graph showing molecular speed vs. relative number of particles]

- A. A
- B. B
- C. C
- D. D
- E. All of the gases have the same molar mass at 0°C.

5. Two aqueous solutions are both at room temperature and are then mixed in a coffee cup calorimeter. The reaction causes the temperature of the resulting solution to rise above room temperature. Which of the following statements is TRUE?
   A. The products have a higher potential energy than the reactants.
   B. This type of experiment will provide data to calculate \( \Delta Z_{\text{end}} \).
   C. The reaction is endothermic.
   D. Energy is leaving the reaction.
   E. None of the above statements are true.
6. When waves of equal amplitude from two sources are out of phase when they interact, it is called _________.
   A. destructive interference
   B. diffraction
   C. constructive interference
   D. effusion
   E. amplitude

7. Which of the following isoelectronic species has the smallest radius?
   A. K⁺   B. Ca²⁺   C. P³⁻   D. S²⁻

8. What type of orbital is associated with the following shape?
   - A: s orbital
   - B: p orbital
   - C: d orbital
   - D: f orbital
   - E: g orbital

9. For which of the following electron transitions would a hydrogen atom emit a photon of the lowest energy?

   A) \( n=\infty \)  B) \( n=\infty \)  C) \( n=\infty \)  D) \( n=\infty \)

   \[
   \begin{array}{cccc}
   n=4 & n=3 & n=3 & n=4 \\
   n=3 & n=2 & n=3 & n=3 \\
   n=2 & n=1 & n=2 & n=1 \\
   n=1 & n=1 & n=1 & n=1 \\
   \end{array}
   \]

10. An open-tube manometer is used to measure the pressure in flask. The atmospheric pressure is 756 torr and the Hg column is 10.5 cm higher on the open end. What is the pressure in the flask?

   A. 766.5 mm Hg
   B. 861 cm Hg
   C. 861 torr
   D. 649 torr
   E. 745.5 mm Hg

11. Which halogen has the greatest first ionization energy?
   (A) F   (B) Cl   (C) Br   (D) I

II. Free Response

1. How much work (in Joules) is done by a gas when it expands from a volume of 1.00 L to a volume of 12.0 L at a constant pressure of 2.50 atm? (6 points)

   \[
   W = -P \Delta V
   \]

   \[
   W = -(12.5 \text{ L} \cdot \text{atm}) \left( \frac{101.325 \text{ L} \cdot \text{atm}}{1 \text{ L} \cdot \text{atm}} \right) = 2758 \text{ J}
   \]

30 point.
2. A 25.0 mL sample of 1.200 M KOH is mixed with a 175.0 mL sample of 0.400 M HCl in a coffee cup calorimeter. If both solutions were initially at 34.25°C and the temperature of the resulting solution was recorded as 36.00°C, determine the ΔH \text{rxn} (in units of kJ/mol) for the neutralization reaction between aqueous KOH and HCl. Assume 1) that no heat is lost to the calorimeter or the surroundings, and 2) that the density and the heat capacity of the resulting solution are the same as water. (14 points)

\[\text{HCl(aq)} + \text{KOH(aq)} \rightarrow \text{H}_2\text{O(l)} + \text{KCl(aq)}\]

\[\text{Q} = MC_s \Delta T \quad \Delta H_{\text{rxn}} = \text{Q}_\text{rxn} \]

\[\text{Q} = (1.75 \text{L})(4.184 \text{J/g°C})(200 \text{g}) = 144,440 \text{J} \]

\[\Delta H_{\text{rxn}} = \frac{144,440 \text{J}}{0.3 \text{mol}} = 481,333 \text{J/mol} \rightarrow 4.81 \times 10^5 \text{J/mol}\]

3. Oxygen gas is generated in the laboratory by thermal decomposition of potassium chlorate, KClO₃. The O₂ is collected over water at a total pressure of 745 mm Hg and a temperature of 30.0°C. What volume of O₂ is generated from decomposition of 1.00 g of KClO₃? (16 points)

\[2 \text{KClO}_3(s) \rightarrow 2 \text{KCl} + 3 \text{O}_2(g)\]

\[\frac{1.06 \text{g KClO}_3}{122.549 \text{g}} = 0.01224 \text{ mol O}_2\]

\[\frac{3 \text{ mol O}_2}{2 \text{ mol KClO}_3} \]

\[P_T = P_{O_2} + P_{H_2O} \quad P_T = 745 \text{ mm Hg} = P_{O_2} + 31.8 \text{ mm Hg}\]

\[P_{O_2} = 713.14 \text{ mm Hg} \]

\[\rho = 0.938 \text{ atm}\]

\[P_{O_2}V = n_{O_2}RT\]

\[(0.01224 \text{ mol})(0.08206 \text{ L atm/mol K})(303.15 \text{ K}) = V(0.938)\]

\[V = 0.325 \text{ L O}_2\]
4. Calculate the energy in kJ/mol that is emitted or absorbed (and state which one it is) in the electron transition from \( n = 3 \) to \( n = 4 \) in the helium ion, \( \text{He}^+ \). (10 points)

\[
E = -2.18 \times 10^{-19} \text{ J} \cdot \frac{2^2}{\frac{1}{2^2}} (\frac{1}{3^2} - \frac{1}{4^2})
\]

\[
E = -2.18 \times 10^{-19} \text{ J} \cdot \frac{2^2}{10} (\frac{1}{3^2} - \frac{1}{4^2}) = 4.24 \times 10^{-19} \text{ J}/\text{e}^-
\]

\[
\frac{4.24 \times 10^{-19} \text{ J}}{1 \text{ e}^-} = \frac{1.09 \times 10^{-23} \text{ e}^-}{1 \text{ mol e}^-} = 255 \text{ kJ/mol absorbed}
\]

5. Write out the full electron configuration (do not use a noble gas core) for the ground state of a nickel (Ni) atom. (6 points)

\[\text{Ni: } 1s^2 \ 2s^2 \ 2p^6 \ 3s^2 \ 3p^6 \ 3d^{8} \ 4s^2 \ 3d^9\]

6. Write out the electron configuration using a noble gas core for the ground state of: (8 points)
   A. Cu atom \( [\text{Ar}] \ 4s^1 \ 3d^{10} \)
   B. \( \text{Cu}^{2+} \) ion \( [\text{Ar}] \ 3d^9 \)

7. Why do the 2s and 2p sublevels in the hydrogen atom have the same energy? (4 points)

   The 2s \& 2p sublevels are the same avg distance from the nucleus

8. Why is the trend in atomic sizes such that atomic size increases down the same column in the periodic table? (4 points)

   Valence e\(^-\) occupy higher levels due to inc. quantum \# in
   the valence e\(^-\) are further away from the nucleus as n inc.
   e\(^-\) shielding prevents outer e\(^-\) from being attracted to the nucleus, so
   they are held loosely \( \Rightarrow \) atomic radius is larger
9. When static electricity discharges, there are some parallels to our use of the gas discharge tube in CHEM 400.

A. The average discharge of static electricity involves 0.00100 J of energy and $2.08 \times 10^{11}$ electrons. Calculate the energy of each electron and the wavelength of light associated with each electron. (10 points)

\[
\frac{0.0013}{2.08 \times 10^{11} \text{e}^{-}} = 4.81 \times 10^{-15} \text{ J/e}^{-}
\]

\[
4.81 \times 10^{-15} \text{ J} = (6.626 \times 10^{-34} \text{ Js})(v)
\]

\[
v = 7.25 \times 10^{19}
\]

\[
\lambda = 4.13 \times 10^{-7} \text{ m}
\]

B. Static electricity discharge can be visible (as shown in the above). With specific relationship to your answer in part A and atomic properties, explain why this is. Calculations can be helpful in your explanation but are not necessary to receive full credit. (12 points)

The wavelength is higher than what is in the visible region. As it comes back down, visible light can be seen.

If the atom absorbs a $4.13 \times 10^{-7}$ m wavelength, it will be very far away from the nucleus and have a large $n$ value.

As the $e^{-}$ comes down, you can see light.
1. Why does the atomic radius of an atom get larger as you go from right to left across the periodic table? Please be specific and mention the n value for the valence electrons and the trend in effective nuclear charge as you go from right to left across the periodic table. (8 points)

2. We talked about at least three separate cases when electron-electron repulsion affected the energy levels of electrons in atoms. Choose one of these cases and explain why electron-electron repulsions are important. (8 points)