Name: ___________________

Attempt all questions in this exam. Read each question carefully and give a complete answer in the space provided.

Part marks given for wrong answers with partially correct reasoning/calculations. A Periodic Table and formula sheet are attached at the back.

Total points = 50

Good Luck.
Section I: (20 points total, 1 point each)
Choose the BEST answer to the following questions.

1–3. Consider three 1-L flasks at STP. Flask A contains NH₃ gas, flask B contains NO₂ gas, and flask C contains N₂ gas. Assume ideal gas behavior.

1. Which contains the smallest number of molecules?
   a) flask A
   b) flask B
   c) flask C
   d) all are the same
   e) none

2. In which flask contains the smallest mass of gas?
   a) flask A
   b) flask B
   c) flask C
   d) all are the same
   e) none

3. In which flask do the molecules have the highest average velocity?
   a) flask A
   b) flask B
   c) flask C
   d) all are the same
   e) none

4. Given a cylinder of fixed volume filled with 1 mol of argon gas, which of the following is correct? (Assume all gases obey the ideal gas law.)
   a) If the temperature of the cylinder is changed from 25°C to 50°C, the pressure inside the cylinder will double.
   b) If a second mole of argon is added to the cylinder, the ratio T/P would remain constant.
   c) A cylinder of identical volume filled with the same pressure of helium must contain more atoms of gas because He has a smaller atomic radius than argon.
   d) Two of the above.
   e) None of the above.

5. Under which conditions of P, T, and n will a gas, most closely act as an ideal gas?
   a) high P, high T, high n
   b) low P, low T, low n
   c) high P, low T, high n
   d) low P, high T, high n
   e) low P, high T, low n
6. Consider the following containers, one with helium at 27°C and the other with argon at 27°C.

Which of the following statements are true?

a) The speed of each atom of helium is 926 m/s.

b) The rms speed of the He and the Ar atoms are the same.

c) The average kinetic energy of the two samples are equal.

d) All of the above are true.

d) none of the above are true.

7. At 200 K, the molecules or atoms of an unknown gas, X, have an average velocity equal to that of Ar atoms at 400 K. What is X? (Assume ideal behavior.)

a) CO

b) C₂O₂

c) HF

d) HBr

e) F₂

8. Consider a sample of gas in a container on a comfortable fall day in Vancouver. The Celsius temperature suddenly doubles, and you transfer the gas to a container with twice the volume of the first container. If the original pressure was 12 atm, what is a good estimate for the new pressure?

a) 3 atm

b) 5.7 atm

c) 6.3 atm

d) 12 atm

e) 15 atm

9. Which of the following is true about the kinetic molecular theory?

a) The volume of a gas particle is considered to be about 0.10 mL.

b) Pressure is due to the collisions of the gas particles with the walls of the container.

c) Gas particles repel each other, but do not attract one another.

d) Adding an ideal gas to a closed container will cause an increase in temperature.

e) At least two of the above statements are correct.
10. Which of the following is the best qualitative graph of \textit{Pressure versus Temperature (K)} of a fixed amount of gas at constant volume?

\begin{itemize}
  \item [a)] \includegraphics[width=1cm]{graph_a.png}
  \item [b)] \includegraphics[width=1cm]{graph_b.png}
  \item [c)] \includegraphics[width=1cm]{graph_c.png}
  \item [d)] \includegraphics[width=1cm]{graph_d.png}
  \item [e)] None of these
\end{itemize}

11. A mixture is prepared from 15.0 L of ammonia and 15.0 L chlorine measured at the same conditions, these compounds react according to the following equation:

\[ 2\text{NH}_3(g) + 3\text{Cl}_2(g) \rightarrow \text{N}_2(g) + 6\text{HCl}(g) \]

When the reaction is completed, what is the volume of each gas (NH$_3$, Cl$_2$, N$_2$, and HCl, respectively)? Assume the final volumes are measured under identical conditions.

\begin{itemize}
  \item [a)] 0.00 L, 5.00 L, 7.50 L, 45.0 L
  \item [b)] 5.00 L, 0.00 L, 5.00 L, 30.0 L
  \item [c)] 0.00 L, 0.00 L, 7.50 L, 45.0 L
  \item [d)] 0.00 L, 0.00 L, 5.00 L, 30.0 L
  \item [e)] 0.00 L, 10.0 L, 15.0 L, 90.0 L
\end{itemize}

12. The van der Waals constants for Ar are \( a = 1.345 \text{ atm L}^2 \text{ mol}^{-2} \) and \( b = 0.03219 \text{ L/mol} \). The same constants for O$_2$ are \( a = 1.360 \text{ atm L}^2 \text{ mol}^{-2} \) and \( b = 0.03183 \text{ L/mol} \). Which of the following is correct in a comparison between Ar and O$_2$?

\begin{itemize}
  \item [a)] Attractions between Ar particles are stronger and the effective size of the Ar particle is greater.
  \item [b)] Attractions between O$_2$ particles are stronger and the effective size of the O$_2$ particle is greater.
  \item [c)] Attractions between O$_2$ particles are stronger but the effective size of the Ar particle is greater.
  \item [d)] Attractions between Ar particles are stronger but the effective size of the O$_2$ particle is greater.
\end{itemize}
13. Hydrogen and chlorine gases react to form HCl. You and a friend are on opposite sides of a long hallway, you with H₂ and your friend with Cl₂. You both want to form HCl in the middle of the room. Which of the following is true?
   a) You should release the H₂ first.
   b) Your friend should release the Cl₂ first.
   c) You both should release the gases at the same time.
   d) You need to know the length of the room to answer this question.
   e) You need to know the temperature to answer this question.

14. Which of the following effects will make \( \frac{PV}{nRT} \) greater than 1 for a real gas?
   a) The gas molecules are large enough to occupy a substantial amount of space.
   b) A large number of molecules have speeds greater than the average speed.
   c) The gas molecules have a very low molar mass.
   d) The gas molecules attract one another.
   e) none of these

15. As part of the quantization of light, Einstein proposed that light could behave as packets of energy referred to as:
   a) photons
   b) protons
   c) electrons
   d) neutrons
   e) neutrinos

16. A beam of light with a wavelength of 450 nm is expelling electrons from a lithium surface. What will be the effect of doubling the intensity of this light that is, employing two lamps instead of one?
   a) No effect
   b) Increase the kinetic energy of expelled electrons
   c) Increase the number of expelled electrons
   d) Increase the kinetic energy and the number of expelled electrons

17. In Bohr’s atomic theory, when an electron moves from one energy level to another energy level more distant from the nucleus.
   a) energy is emitted.
   b) energy is absorbed.
   c) no change in energy occurs.
   d) light is emitted.
   e) none of these
18. Light is best described as:
   a) a particle
   b) a wave
   c) both a particle and a wave

19. The energy of the light emitted when a hydrogen electron goes from \( n = 2 \) to \( n = 1 \) is what fraction of its ground-state ionization energy?
   a) 3/4
   b) 1/2
   c) 1/4
   d) 1/8
   e) 1/9

20. In an investigation of the electronic absorption spectrum of a particular element, it is found that a photon having \( \lambda = 500 \) nm provides just enough energy to promote an electron from the second quantum level to the third. From this information, we can deduce
   a) the energy of the \( n = 2 \) level.
   b) the energy of the \( n = 3 \) level.
   c) the sum of the energies of \( n = 2 \) and \( n = 3 \).
   d) the difference in energies between \( n = 2 \) and \( n = 3 \).
   e) all of these

Section II: Calculations and reasoning must be shown (30 points total)

21. During a manufacturing process, a pocket of gas at 250°C formed a bubble inside of a liquid mass. The bubble had a volume of 325 mL at the time of its formation. What is the volume of his bubble now that the product is in a 20°C storage facility? Assume that the pressure is constant, no gas leaked out and that the gas behaves as an ideal gas. (2 points)

\[
\frac{V_1}{T_1} = \frac{V_2}{T_2} \implies V_2 = \frac{V_1 T_2}{T_1} = \frac{(325 \text{ mL})(20 + 273 K)}{(250 + 273 K)} = 182 \text{ mL}
\]
22. A big league fastball travels at about 45 m/s. At what temperature (°C) do helium atoms have this average velocity? (2 points)

\[ v_{avg} = \sqrt{\frac{8RT}{\pi M}} \rightarrow T = \frac{\pi Mv_{avg}^2}{8R} \]

\[ T = \frac{\pi Mv_{avg}^2}{8R} = \frac{\pi \left( \frac{4.0 \text{ g}}{\text{mol}} \right) \left( \frac{kg}{1000 \text{ g}} \right) (45 \text{ m s}^{-1})^2}{8(8.314 \text{ J mol}^{-1} \text{ K}^{-1})} = 0.38 \text{ K} \]

\[ T(°C) = 0.38 \text{ K} - 273.15 = 272.77 °C \]

23. Alka-Seltzer contains sodium bicarbonate, NaHCO₃, and citric acid, a source of H⁺. When Alka-Seltzer is dissolved in water the following reactions occur

\[ \text{NaHCO}_3(s) \rightarrow \text{Na}^+(aq) + \text{HCO}_3^-(aq) \]

\[ \text{H}^+(aq) + \text{HCO}_3^-(aq) \rightarrow \text{H}_2\text{O}(ℓ) + \text{CO}_2(g) \]

So the overall reaction is

\[ \text{H}^+(aq) + \text{NaHCO}_3(s) \rightarrow \text{Na}^+(aq) + \text{H}_2\text{O}(ℓ) + \text{CO}_2(g) \]

Alka-Seltzer contains 2.0 g of NaHCO₃. Assume that these reactions go to completion. The reaction is done in a 25 mL fixed volume container at 20°C that has an initial pressure of 1.0 atm. What will be the final pressure (in atm) in the container? Assume ideal gas behavior. (4 points)

\[ (2.0 \text{ g NaHCO}_3) \left( \frac{\text{mol NaHCO}_3}{84.0 \text{ g NaHCO}_3} \right) \left( \frac{1 \text{ mol CO}_2}{\text{mol NaHCO}_3} \right) = 2.38 \times 10^{-2} \text{ mol CO}_2 \]

\[ P_{CO_2} = \frac{n_{CO_2}RT}{V} = \frac{(2.38 \times 10^{-2} \text{ mol CO}_2)(0.08206 \text{ L atm mol}^{-1} \text{ K}^{-1})(293 \text{ K})}{0.025 \text{ L}} = 23 \text{ atm} \]

\[ P_0 = 1 \text{ atm} \]

\[ P_T = P_0 + P_{CO_2} = 1 \text{ atm} + 23 \text{ atm} = 24 \text{ atm} \]
A 10.0 L flask at 25°C contains 2.00 mol of gasoline vapor (the term “vapor” is usually used for the gaseous state of compounds that would normally be considered liquids)

a). Calculate the pressure using the ideal gas law (2 points)

\[ P = \frac{nRT}{V} = \frac{(2.00 \text{ mol})(0.08206 \text{ L atm mol}^{-1}\text{ K}^{-1})(25 + 273 \text{ K})}{10.0 \text{ L}} = 4.89 \text{ atm} \]

b) Calculate the pressure using the van der Waals equation. Use the a and b values for isoctane
a = 25.43 atm L² mol⁻² and b = 0.1453 L/mol (3 points)

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

\[ P = \frac{(2.00 \text{ mol})(0.08206 \text{ L atm mol}^{-1}\text{ K}^{-1})(25 + 273 \text{ K})}{10.0 \text{ L} - (2.00 \text{ mol})(0.1453 \text{ L/mol})} - (25.43 \text{ atm L}^2 \text{ mol}^{-2}) \left( \frac{2 \text{ mol}}{10.0 \text{ L}} \right)^2 \]

\[ P = 4.02 \text{ atm} \]

c) Comment on if gasoline vapor behaves as an ideal gas under these conditions. If not what is the major cause of the deviation? Hint: consider the compressibility factor. (2 points)

\[ Z = \frac{PV}{nRT} = \frac{(4.02 \text{ atm})(10.0 \text{ L})}{(2.00 \text{ mol})(0.08206 \text{ L atm mol}^{-1}\text{ K}^{-1})(25 + 273 \text{ K})} = 0.82 \]

The ~ 20% difference in pressure shows that the gasoline vapor significantly differs from an ideal gas. Since Z = 0.82 < 1 the dominant deviation is that there is significant attraction between the molecules under these conditions. In fact so non-ideal that it will condense into a liquid.
25. Molecular oxygen, $O_2$, is split or dissociated into a pair of atoms by radiation from the sun. The lowest frequency of light that can cause the reaction is $1.21 \times 10^{15} \text{ s}^{-1}$.

a). What is the energy necessary to split the $O_2$ molecule (2 points)

$$E = hf = (6.63 \times 10^{-34} \text{ J s}) (1.21 \times 10^{15} \text{ s}^{-1}) = 8.02 \times 10^{-19} \text{ J}$$

b). What is longest wavelength light that can split the $O_2$ molecule (2 points)

$$\lambda = \frac{c}{f} = \frac{3.00 \times 10^8 \text{ m/s}}{1.21 \times 10^{15} \text{ s}^{-1}} = 2.48 \times 10^{-7} \text{ m} = 248 \text{ nm}$$

26. The electron binding energy of potassium metal is $3.60 \times 10^{-19} \text{ J}$. What is the kinetic energy for photoelectrons expelled from potassium metal by light at 488 nm? (3 points)

$$E_{\text{electron}} = E_{\text{photon}} - E_{\text{binding}} = \frac{hc}{\lambda} - E_{\text{binding}}$$

$$E_{\text{electron}} = \frac{(6.63 \times 10^{-34} \text{ J s})(3.00 \times 10^8 \text{ m/s})}{488 \times 10^{-9} \text{ m}} - 3.60 \times 10^{-19} \text{ J} = 4.8 \times 10^{-20} \text{ J}$$
27. An atom has a velocity of 75 m/sec and a de Broglie wavelength of $2.19 \times 10^{-10}$ m. What is the element? (3 points)

$$\lambda = \frac{h}{mv} \Rightarrow m = \frac{h}{\lambda v} = \frac{6.63 \times 10^{-34} J \cdot s}{(2.19 \times 10^{-10} \text{ m})(75 \text{ m/s})} = 4.0 \times 10^{-26} \text{ kg}$$

$$\text{At. Wt.} = mN_A = (4.0 \times 10^{-26} \text{ kg}) \left( \frac{1000 \text{ g}}{\text{kg}} \right) \left( \frac{6.02 \times 10^{23}}{\text{mol}} \right) = 24.3 \text{ g/mol}$$

$$\therefore \text{ element is Mg}$$

28. Which electron is in a larger orbit, a n=1 electron on a H atom or an n=2 electron on a Li$^{2+}$ ion? Explain your reasoning. (2 points)

$$r = \frac{n^2}{Z} a_o$$

For H atom; $r = \frac{1^2}{1} a_o = a_o = 52.9 \text{ pm}$

For Li$^{2+}$ ion; $r = \frac{2^2}{3} a_o = \frac{4}{3} a_o = 70.5 \text{ pm}$

$$\therefore \text{ the n=2 Li}^{2+} \text{ ion is larger.}$$

29. The electrons in a cathode ray tube have energy of about $1.00 \times 10^3$ eV. If the electron’s momentum is known to 1%, what is the minimum uncertainty in the position of the electron? (3 points)

$$KE = \frac{1}{2} mv^2 \Rightarrow p = mv = \sqrt{2mKE}$$

$$p = \sqrt{2(9.11 \times 10^{-31} \text{ kg})(1.00 \times 10^3 \text{ eV}) \left( \frac{1.602 \times 10^{-19} \text{ J}}{\text{eV}} \right)} = 1.71 \times 10^{-23} \text{ kg m s}^{-1}$$

$$\Delta p = 0.01 p = 1.71 \times 10^{-25} \text{ kg m s}^{-1}$$

$$\Delta x \Delta p \geq \frac{h}{4\pi}$$

$$\Delta x_{min} = \frac{h}{4\pi \Delta p} = \frac{6.63 \times 10^{-34} \text{ J s}}{4\pi(1.71 \times 10^{-25} \text{ kg m s}^{-1})} = 3.09 \times 10^{-10} \text{ m}$$
Equations and Formulas

\[ PV = nRT \]

\[ (P + \frac{an^2}{V^2})(V - nb) = nRT \]

\[ Z = \frac{PV}{nRT} \]

\[ KE_{avg} = \frac{3}{2}RT \quad KE = \frac{1}{2}mv^2 \]

\[ F(v) = 4\pi \left( \frac{m}{2\pi kT} \right)^{\frac{3}{2}} v^2 e^{-\frac{mv^2}{2kT}} \]

\[ v_{mp} = \sqrt{\frac{2kT}{m}} = \sqrt{\frac{2RT}{M}} \quad v_{avg} = \sqrt{\frac{8kT}{\pi m}} = \sqrt{\frac{8RT}{\pi M}} \quad v_{rms} = \sqrt{\frac{3kT}{m}} = \sqrt{\frac{3RT}{M}} \]

\[ T(K) = T(°C) + 273.15 \]

\[ R = 0.0820575 \text{ L atm mol}^{-1} \text{ K}^{-1} = 8.314 \text{ J mol}^{-1} \text{ K}^{-1} = 8.314 \text{ Pa m}^3 \text{ mol}^{-1} \text{ K}^{-1} \]

\[ 1 \text{ atm} = 760 \text{ T} = 760 \text{ mm Hg} = 101,325 \text{ Pa} \]

\[ k = 1.38 \times 10^{-23} \text{ J/K} \]

\[ c = 3.00 \times 10^8 \text{ m/s} \]

\[ m_e = 9.11 \times 10^{-31} \text{ kg} \]

\[ h = 6.63 \times 10^{-34} \text{ J s} \]

\[ N_A = 6.02 \times 10^{23} \]

\[ 1 \text{ eV} = 1.602 \times 10^{-19} \text{ J} \]

\[ g = 9.81 \text{ m s}^{-2} \]

\[ P = hgd \]

\[ E_n = -2.178 \times 10^{-18} \text{ J} \left( \frac{Z^2}{n^2} \right) \Delta E = (2.178 \times 10^{-18} J)(Z^2) \left( \frac{1}{n_2^2} - \frac{1}{n_1^2} \right) \]

\[ \frac{1}{\lambda} = (109,678 \text{ cm}^{-1})(Z^2) \left( \frac{1}{n_2^2} - \frac{1}{n_1^2} \right) \]

\[ r = \frac{n^2}{Z} a_0 \]

\[ a_0 = 52.9 \text{ pm} \]

\[ p = mv \quad E = hf \quad c = \lambda f \quad \lambda = \frac{h}{mv} \quad \Delta x \Delta p_x \geq \frac{h}{4\pi} \]

\[ E_{photon} = E_{binding} + E_{electron} \]
# Periodic Table of the Elements

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Based on mass of C₁² at 12.00
Values in parenthesis are the masses of the most stable or best known isotopes for elements which do not occur naturally.