Phy 212: General Physics II  
Chapter 19 Worksheet

**Boltzmann Constant:** \( k = 1.38 \times 10^{-23} \text{ J/K} \)

**Gas Constant:** \( R = 8.314 \text{ J/mol·K} \)

**Molar Mass & Avogadro’s Number:**

1. Determine the atomic mass for the following elements: {from the textbook}
   
   a) hydrogen (H): 1.00797 g/mol
   b) argon (Ar): 39.948 g/mol
   c) carbon (C): 12.01115 g/mol
   d) oxygen (O): 15.9994 g/mol

2. Determine the molecular mass for the following compounds:
   
   a) oxygen gas (O\(_2\)): 31.9988 g/mol
   b) carbon dioxide (CO\(_2\)): 44.00995 g/mol
   c) methane (CH\(_4\)): 16.4303 g/mol

3. Determine the molar quantity of the following:
   
   a) 0.10 kg of Ar: 2.5 mol
   b) 0.010 kg of O\(_2\): 3.1 mol
   c) 0.15 kg of CO\(_2\): 3.4 mol
   d) 1.0 kg methane (CH\(_4\)): 62.3 mol

4. Determine the number of molecules for the following:
   
   a) 0.10 kg of Ar: 1.5x10\(^{24}\) atoms
   b) 0.010 kg of O\(_2\): 1.9x10\(^{24}\) molecules
   c) 0.15 kg of CO\(_2\): 2.1x10\(^{24}\) molecules
   d) 1.0 kg methane (CH\(_4\)): 3.8x10\(^{25}\) molecules

5. A sample of monatomic ideal gas is originally at 20°C. What is the final temperature of the gas if both the pressure and volume are doubled?

   \[
   \text{Ans. } \frac{P_2 V_2}{T_2} = \frac{P_1 V_1}{T_1} \Rightarrow T_2 = T_1 \left( \frac{P_2 V_2}{P_1 V_1} \right) = (293.15K) \left( \frac{4P_1 V_1}{P_1 V_1} \right) = 1172.6K
   \]

6. Heat is absorbed by a sample of a monatomic ideal gas at 40 °C. It is observed that the gas expands until its volume is doubled and the pressure drops to half of its original value. What is the final temperature of the gas?

   \[
   \text{Ans. } \frac{P_2 V_2}{T_2} = \frac{P_1 V_1}{T_1} \Rightarrow T_2 = T_1 \left( \frac{P_2 V_2}{P_1 V_1} \right) = (313.15K) \left( \frac{\frac{1}{2} P_1 2V_1}{P_1 V_1} \right) = 313.15K
   \]
7. A canister containing 150 kg of an ideal gas has a volume of 8.0 m$^3$. If the gas exerts a pressure of $5.0 \times 10^5$ Pa, what is the $rms$ speed of the molecules?

Ans. $\frac{PV}{nRT} = \frac{(5.0 \times 10^5 \text{Pa}) (8.0 \text{m}^3)}{4.0 \times 10^6} \Rightarrow v_{rms} = \sqrt{\frac{3nRT}{m}} = \sqrt{\frac{3PV}{m}} = 282.8 \text{ m/s}$

8. A tank contains 135 moles of the monatomic gas, argon, at a temperature of 15.3 °C. How much energy must be added to the gas to increase its temperature to 45.0 °C?

Ans. $Q = \frac{3}{2} nR \Delta T = \frac{3}{2} (135 \text{mol})(8.314 \text{ J/mol} \cdot \text{K})(29.7 \text{K}) = 5.00 \times 10^4 \text{J}$

9. An ideal gas with a fixed number of molecules is maintained at a constant pressure. At 30.0 °C, the volume of the gas is 1.50 m$^3$. What is the volume when the temperature is increased to 75.0 °C?

Ans. $\frac{V_2}{T_2} = \frac{V_1}{T_1} \Rightarrow V_2 = T_2 \left( \frac{V_1}{T_1} \right) = (348.15 \text{K}) \left( \frac{1.5 \text{m}^3}{303.15 \text{K}} \right) = 1.7 \text{m}^3$

**Constant Temperature (Isothermal) Processes:**

1. A sample of 10.0 moles of a monatomic ideal gas, held at constant temperature (1000K), is expanded from 0.10 m$^3$ to 0.20 m$^3$.

a. What is the initial pressure of the gas, before heating?

Ans. $P = \frac{nRT}{V} = \frac{(10 \text{mol})(8.314 \text{ J/mol} \cdot \text{K})(1000 \text{K})}{(0.10 \text{m}^3)} = 8.31 \times 10^5 \text{Pa}$

b. What is the initial internal energy of the gas?

Ans. $E_{int} = \frac{3}{2} nRT = \frac{3}{2} (10 \text{mol})(8.314 \text{ J/mol} \cdot \text{K})(1000 \text{K}) = 1.25 \times 10^5 \text{J}$

c. How much work is performed by the gas during the heating process?

Ans. $W = nRT \cdot \ln \left( \frac{V_2}{V_1} \right) = (10.0 \text{mol})(8.314 \text{ J/mol} \cdot \text{K})(1000 \text{K}) \cdot \ln(2) = 5.76 \times 10^4 \text{J}$

d. What is the final internal energy of the gas?

Ans. Since $\Delta T = 0 \text{K}$, $E_{int,f} = E_{int,i} = 1.25 \times 10^5 \text{J}$

e. What is the change in internal energy of the gas?

Ans. $E_{int} = 0 \text{ J}$

f. Conceptually, is heat absorbed or released by the gas during the compression?

Ans. $Q$ is absorbed since the gas does work but $E_{int}$ doesn't change.

g. Calculate the amount of heat absorbed/released by the gas?

Ans. $\Delta E_{int} = Q - W = 0 \text{ J}$ or $Q = W = 5.76 \times 10^4 \text{J}$
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**Constant Pressure (Isobaric) Processes:**

2. A sample of 10.0 moles of a monatomic ideal gas, held at constant pressure (1.5 atm or 1.52x10^5 Pa), is compressed from 0.10 m^3 to 0.05 m^3.

a. What is the initial temperature of the gas, before the compression?

Ans. \[ T = \frac{PV}{nR} = \frac{(1.52 \times 10^5 \text{ Pa})(0.10 \text{ m}^3)}{(10.0 \text{ mol})(8.314 \text{ J/mol\cdot K})} = 182.8 \text{ K} \]

b. What is the initial internal energy of the gas?

Ans. \[ E_{\text{int}} = \frac{3}{2} nRT = \frac{3}{2} PV = \frac{3}{2}(1.52 \times 10^5 \text{ Pa})(0.10 \text{ m}^3)=2.28 \times 10^4 \text{ J} \]

c. How much work is performed by the gas during the compression?

Ans. \[ W = p\Delta V = (1.52 \times 10^5 \text{ Pa})(0.4 \text{ m}^3) = 6.08 \times 10^4 \text{ J} \]

d. What is the final temperature of the gas?

Ans. \[ T = \frac{PV}{nR} = \frac{(1.52 \times 10^5 \text{ Pa})(0.50 \text{ m}^3)}{(10.0 \text{ mol})(8.314 \text{ J/mol\cdot K})} = 914.0 \text{ K} \]

e. What is the change in internal energy of the gas?

Ans. \[ \Delta E_{\text{int}} = \frac{3}{2} nR\Delta T = \frac{3}{2}(10.0 \text{ mol})(8.314 \text{ J/mol\cdot K})(731.2 \text{ K})= 9.12 \times 10^4 \text{ J} \]

f. Conceptually, is heat absorbed or released by the gas during the compression?

Ans. Both \( E_{\text{int}} \) and \( W \) have increased; this requires that \( Q \) be absorbed to account for the additional energy.

g. Calculate the amount of heat absorbed/released by the gas?

Ans. \[ Q = \Delta E_{\text{int}} + W = 9.12 \times 10^4 \text{ J} + 6.08 \times 10^4 \text{ J} = 1.52 \times 10^5 \text{ J} \]

3. A sample of 5.0 moles of a monatomic ideal gas, held at constant pressure (2.0 atm or 2.026x10^5 Pa), is expanded from 0.05 m^3 to 0.10 m^3.

a. What is the initial temperature of the gas, before the compression?

Ans. \[ T = \frac{PV}{nR} = \frac{(2.026 \times 10^5 \text{ Pa})(0.05 \text{ m}^3)}{(5.0 \text{ mol})(8.314 \text{ J/mol\cdot K})} = 243.7 \text{ K} \]

b. What is the initial internal energy of the gas?

Ans. \[ E_{\text{int}} = \frac{3}{2} nRT = \frac{3}{2} PV = \frac{3}{2}(2.026 \times 10^5 \text{ Pa})(0.05 \text{ m}^3)= 1.52 \times 10^4 \text{ J} \]

c. How much work is performed by the gas during the compression?

Ans. \[ W = p\Delta V = (2.026 \times 10^5 \text{ Pa})(0.05 \text{ m}^3) = 1.01 \times 10^4 \text{ J} \]

d. What is the final temperature of the gas?

Ans. \[ T = \frac{PV}{nR} = \frac{(2.026 \times 10^5 \text{ Pa})(0.10 \text{ m}^3)}{(5.0 \text{ mol})(8.314 \text{ J/mol\cdot K})} = 487.4 \text{ K} \]

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Gas Constant: \( R = 8.314 \text{ J/mol} \cdot \text{K} \)

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e. What is the change in internal energy of the gas?
   \[
   \Delta E_{\text{int}} = \frac{3}{2} nR \Delta T = \frac{3}{2} (5.0 \text{ mol})(8.314 \frac{\text{J}}{\text{mol} \cdot \text{K}})(243.7 \text{ K}) = 1.52 \times 10^4 \text{ J}
   \]

f. Conceptually, is heat absorbed or released by the gas during the compression?
   Ans. Both \( E_{\text{int}} \) and \( W \) have increased; this requires that \( Q \) be absorbed to account for the additional energy.

g. Calculate the amount of heat absorbed/released by the gas?
   \[
   Q = \Delta E_{\text{int}} + W = 1.52 \times 10^4 \text{ J} + 1.01 \times 10^4 \text{ J} = 2.53 \times 10^4 \text{ J}
   \]

**Constant Volume (Isochoric) Processes:**

4. A sample of 10.0 moles of a monatomic ideal gas, held at constant volume (1.0 m\(^3\)), is heated from 300 K to 400 K.

a. What is the initial pressure of the gas, before heating?
   \[
   P = \frac{nRT}{V} = \frac{(10 \text{ mol})(8.314 \frac{\text{J}}{\text{mol} \cdot \text{K}})(300 \text{ K})}{(1.0 \text{ m}^3)} = 2.49 \times 10^4 \text{ Pa}
   \]

b. What is the initial internal energy of the gas?
   \[
   E_{\text{int}} = \frac{3}{2} nRT = \frac{3}{2} (2.49 \times 10^4 \text{ Pa}) = 3.74 \times 10^4 \text{ J}
   \]

c. How much work is performed on the gas during the heating process?
   Ans. \( W = 0 \text{ J} \)

d. What is the final internal energy of the gas?
   \[
   E_{\text{int}} = \frac{3}{2} nRT = \frac{3}{2} (10.0 \text{ mol})(8.314 \frac{\text{J}}{\text{mol} \cdot \text{K}})(400 \text{ K}) = 4.99 \times 10^4 \text{ J}
   \]

e. What is the change in internal energy of the gas?
   \[
   \Delta E_{\text{int}} = \frac{3}{2} nR \Delta T = \frac{3}{2} (10.0 \text{ mol})(8.314 \frac{\text{J}}{\text{mol} \cdot \text{K}})(100 \text{ K}) = 1.25 \times 10^4 \text{ J}
   \]

f. Conceptually, is heat absorbed or released by the gas during the compression?
   Ans. Since \( E_{\text{int}} \) increases, \( Q \) must be absorbed to account for the additional energy.

g. Calculate the amount of heat absorbed/released by the gas?
   \[
   Q = \Delta E_{\text{int}} = 1.25 \times 10^4 \text{ J}
   \]

4. A sample of 10.0 moles of a diatomic ideal gas, held at constant volume (1.0 m\(^3\)), is heated from 250 K to 400 K.

a. What is the initial pressure of the gas, before heating?
   \[
   P = \frac{nRT}{V} = \frac{(10 \text{ mol})(8.314 \frac{\text{J}}{\text{mol} \cdot \text{K}})(250 \text{ K})}{(1.0 \text{ m}^3)} = 2.08 \times 10^4 \text{ Pa}
   \]

b. What is the initial internal energy of the gas?
   \[
   E_{\text{int}} = \frac{5}{2} nRT = \frac{5}{2} (2.08 \times 10^4 \text{ Pa}) = 5.20 \times 10^4 \text{ J}
   \]
c. How much work is performed on the gas during the heating process?
Ans. $W = 0 \text{ J}$

d. What is the final internal energy of the gas?
Ans. $E_{\text{int}} = \frac{5}{2} nRT = \frac{5}{2} (10.0 \text{ mol})(8.314 \text{ J/mol K})(400. \text{ K}) = 8.31 \times 10^4 \text{ J}$

e. What is the change in internal energy of the gas?
Ans. $\Delta E_{\text{int}} = \frac{5}{2} nR\Delta T = \frac{5}{2} (10.0 \text{ mol})(8.314 \text{ J/mol K})(150. \text{ K}) = 3.12 \times 10^4 \text{ J}$

f. Conceptually, is heat absorbed or released by the gas during the compression?
Ans. Since $E_{\text{int}}$ increases, $Q$ must be absorbed to account for the additional energy.

g. Calculate the amount of heat absorbed/released by the gas?
Ans. $Q = \Delta E_{\text{int}} = 3.12 \times 10^4 \text{ J}$

Adiabatic Processes:
5. A sample of 1.5 moles of a thermally insulated (adiabatic) monatomic ideal gas is expanded from 0.10 m$^3$ to 0.20 m$^3$. During the expansion, the pressure of the gas decreases from $3.039 \times 10^5 \text{ Pa}$ to $0.957 \times 10^5 \text{ Pa}$

a. What is the initial temperature of the gas, before adiabatic expansion?
Ans. $T_i = \frac{pV}{nR} = \frac{(0.10 \text{ m}^3)(3.39 \times 10^5 \text{ Pa})}{(1.5 \text{ mol})(8.314 \text{ J/mol K})} = 2440 \text{ K}$

b. What is the final temperature of the gas, after adiabatic expansion?
Ans. $T_f = \frac{pV}{nR} = \frac{(0.957 \times 10^5 \text{ Pa})(0.20 \text{ m}^3)}{(1.5 \text{ mol})(8.314 \text{ J/mol K})} = 1530 \text{ K}$

c. What is the change in internal energy of the gas?
Ans. $\Delta E_{\text{int}} = \frac{\gamma}{\gamma-1} nR\Delta T = \frac{\gamma}{\gamma-1} (1.5 \text{ mol})(8.314 \text{ J/mol K})(-910. \text{ K}) = -1.70 \times 10^4 \text{ J}$

d. How much heat is gained by the gas during this process?
Ans. $Q = 0 \text{ J}$ (adiabatic process!)

e. How much work is performed by the gas during the heating process?
Ans. $W = -\Delta E_{\text{int}} = 1.70 \times 10^4 \text{ J}$
6. A sample of 5.0 moles of a thermally insulated (adiabatic) monatomic ideal gas is expanded from 0.10 m$^3$ to 0.20 m$^3$. During the expansion, the temperature of the gas decreases from 800 K to 500 K.

a. What is the initial pressure of the gas, before adiabatic expansion?

Ans. \[ P_i = \frac{nRT}{V} = \frac{(5.0\text{mol})(8.314 \frac{\text{J}}{\text{mol} \cdot \text{K}})(800\text{K})}{(0.10\text{m}^3)} = 3.33 \times 10^5 \text{Pa} \]
b. What is the final pressure of the gas, after adiabatic expansion?

Ans. \[ P_f = \frac{nRT}{V} = \frac{(5.0 \text{ mol})(8.314 \frac{J}{\text{molK}})(500\text{K})}{(0.20\text{m}^3)} = 1.04 \times 10^5 \text{Pa} \]

c. What is the change in internal energy of the gas?

Ans. \[ \Delta E_{\text{int}} = \frac{3}{2} nR\Delta T = \frac{3}{2}(5.0 \text{ mol})(8.314 \frac{J}{\text{molK}})(-300. \text{ K}) = -1.87 \times 10^4 \text{J} \]

d. How much work is performed by the gas during the process?

Ans. \[ W = -\Delta E_{\text{int}} = 1.87 \times 10^4 \text{J} \]