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: $1.5\text{x}10^{24}$ atoms

b) 0.010 kg of O_2: $1.9\text{x}10^{24}$ molecules

c) 0.15 kg of CO_2: $2.1\text{x}10^{24}$ molecules

d) 1.0 kg methane (CH_4): $3.8\text{x}10^{25}$ 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?

Ans. $\frac{P_2V_2}{T_2} = \frac{P_1V_1}{T_1} \Rightarrow T_2 = T_1\left(\frac{P_2V_2}{P_1V_1}\right) = (293.15\text{K})\left(\frac{4P_1V_1}{P_1V_1}\right) = 1172.6\text{K}$

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?

Ans. $\frac{P_2V_2}{T_2} = \frac{P_1V_1}{T_1} \Rightarrow T_2 = T_1\left(\frac{P_2V_2}{P_1V_1}\right) = (313.15\text{K})\left(\frac{\frac{P_1}{2}\cdot 2V_1}{P_1V_1}\right) = 313.15\text{K}$

Boltzmann Constant: $k = 1.38\text{x}10^{-23}$ J/K
Gas Constant: $R = 8.314\ ^{\text{J}}/_{\text{mol}\cdot\text{K}}$

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 × 10^5 Pa, what is the *rms* speed of the molecules?

Ans. $PV = nRT = (5.0\times10^5 Pa)(8.0 m^3) = 4.0\times10^6 J \Rightarrow v_{rms} = \sqrt{\frac{3nRT}{m}} = \sqrt{\frac{3PV}{m}} = 282.8\ \frac{m}{s}$

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. $Q = \frac{3}{2}nR\Delta T = \frac{3}{2}(135 mol)(8.314 \frac{J}{mol\cdot K})(29.7K) = 5.00\times10^4 J$

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 of the gas when the temperature is increased to 75.0 °C?

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

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. $P = \frac{nRT}{V} = \frac{(10 mol)(8.314 \frac{J}{mol\cdot K})(1000K)}{(0.10m^3)} = 8.31\times10^5 Pa$

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

Ans. $E_{int} = \frac{3}{2}nRT = \frac{3}{2}(10 mol)(8.314 \frac{J}{mol\cdot K})(1000K) = 1.25\times10^5 J$

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

Ans. $W = nRT\cdot\ln\left(\frac{V_2}{V_1}\right) = (10.0 mol)(8.314 \frac{J}{mol\cdot K})(1000K)\cdot\ln(2) = 5.76\times10^4 J$

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

Ans. Since $\Delta T = 0$ K, $E_{int_i} = E_{int_f} = 1.25\times10^5 J$

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

Ans. $E_{int} = 0$ 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. $\Delta E_{int} = Q - W = 0$ J or $Q = W = 5.76\times10^4 J$

Boltzmann Constant: k = 1.38x10^{-23} J/K
Gas Constant: R = 8.314 $^J/_{mol\cdot K}$

Constant Pressure (Isobaric) Processes:

2. A sample of 10.0 moles of a monatomic ideal gas, held at constant pressure (1.5 atm or $1.52\text{x}10^5$ 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. $T = \frac{PV}{nR} = \frac{(1.52\times10^5\text{Pa})(0.10\text{m}^3)}{(10.0\text{ mol})(8.314\frac{\text{J}}{\text{mol}\cdot\text{K}})} = 182.8\text{K}$

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

Ans. $E_{int} = \frac{3}{2}nRT = \frac{3}{2}PV = \frac{3}{2}(1.52\times10^5\text{Pa})(0.10\text{m}^3)=2.28\times10^4\text{J}$

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

Ans. $W = p\Delta V = (1.52\times10^5\text{Pa})(0.4\text{m}^3) = 6.08\times10^4\text{J}$

d. What is the final temperature of the gas?

Ans. $T = \frac{PV}{nR} = \frac{(1.52\times10^5\text{Pa})(0.50\text{m}^3)}{(10.0\text{ mol})(8.314\frac{\text{J}}{\text{mol}\cdot\text{K}})} = 914.0\text{ K}$

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

Ans. $\Delta E_{int} = \frac{3}{2}nR\Delta T = \frac{3}{2}(10.0\text{ mol})(8.314\frac{\text{J}}{\text{mol}\cdot\text{K}})(731.2\text{ K})= 9.12\times10^4\text{J}$

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

Ans. Both E_{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. $Q = \Delta E_{int} + W = 9.12\times10^4\text{J} + 6.08\times10^4\text{J} = 1.52\times10^5\text{J}$

3. A sample of 5.0 moles of a monatomic ideal gas, held at constant pressure (2.0 atm or $2.026\text{x}10^5$ 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. $T = \frac{PV}{nR} = \frac{(2.026\times10^5\text{Pa})(0.05\text{m}^3)}{(5.0\text{ mol})(8.314\frac{\text{J}}{\text{mol}\cdot\text{K}})} = 243.7\text{K}$

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

Ans. $E_{int} = \frac{3}{2}nRT = \frac{3}{2}PV = \frac{3}{2}(2.026\times10^5\text{Pa})(0.05\text{m}^3)= 1.52\times10^4\text{J}$

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

Ans. $W = p\Delta V = (2.026\times10^5\text{Pa})(0.05\text{m}^3) = 1.01\times10^4\text{J}$

d. What is the final temperature of the gas?

Ans. $T = \frac{PV}{nR} = \frac{(2.026\times10^5\text{Pa})(0.10\text{m}^3)}{(5.0\text{ mol})(8.314\frac{\text{J}}{\text{mol}\cdot\text{K}})} = 487.4\text{K}$

Boltzmann Constant: $k = 1.38\text{x}10^{-23}$ J/K
Gas Constant: $R = 8.314\ {}^{J}/_{mol\cdot K}$

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

Ans. $\Delta E_{int} = \frac{3}{2}nR\Delta T = \frac{3}{2}(5.0\text{ mol})(8.314\frac{J}{mol\cdot K})(243.7\text{ K}) = 1.52\times10^{4}J$

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

Ans. Both E_{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. $Q = \Delta E_{int} + W = 1.52\times10^{4}J + 1.01\times10^{4}J = 2.53\times10^{4}J$

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?

Ans. $P = \frac{nRT}{V} = \frac{(10mol)(8.314\frac{J}{mol\cdot K})(300K)}{(1.0m^{3})} = 2.49\times10^{4}Pa$

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

Ans. $E_{int} = \frac{3}{2}nRT = \frac{3}{2}(2.49\times10^{4}Pa) = 3.74\times10^{4}J$

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

Ans. W = 0 J

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

Ans. $E_{int} = \frac{3}{2}nRT = \frac{3}{2}(10.0\text{ mol})(8.314\frac{J}{mol\cdot K})(400.\text{ K}) = 4.99\times10^{4}J$

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

Ans. $\Delta E_{int} = \frac{3}{2}nR\Delta T = \frac{3}{2}(10.0\text{ mol})(8.314\frac{J}{mol\cdot K})(100.\text{ K}) = 1.25\times10^{4}J$

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

Ans. Since E_{int} increases, Q must be absorbed to account for the additional energy.

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

Ans. $Q = \Delta E_{int} = 1.25\times10^{4}J$

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?

Ans. $P = \frac{nRT}{V} = \frac{(10mol)(8.314\frac{J}{mol\cdot K})(250K)}{(1.0m^{3})} = 2.08\times10^{4}Pa$

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

Ans. $E_{int} = \frac{5}{2}nRT = \frac{5}{2}(2.08\times10^{4}Pa) = 5.20\times10^{4}J$

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

Ans. $W = 0\ J$

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

Ans. $E_{int} = \frac{5}{2}nRT = \frac{5}{2}(10.0\ mol)(8.314\frac{J}{mol\cdot K})(400.\ K) = 8.31\times10^4 J$

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

Ans. $\Delta E_{int} = \frac{5}{2}nR\Delta T = \frac{5}{2}(10.0\ mol)(8.314\frac{J}{mol\cdot K})(150.\ K) = 3.12\times10^4 J$

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

Ans. Since E_{int} increases, Q must be absorbed to account for the additional energy.

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

Ans. $Q = \Delta E_{int} = 3.12\times10^4 J$

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 $3.039\text{x}10^5$ Pa to $0.957\text{x}10^5$ Pa

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

Ans. $$T_i = \frac{PV}{nR} = \frac{(0.10m^3)(3.39\times10^5 Pa)}{(1.5mol)(8.314\frac{J}{mol\cdot K})} = 2440K$$

b. What is the final temperature of the gas, after adiabatic expansion?

Ans. $$T_f = \frac{PV}{nR} = \frac{(0.957\times10^5 Pa)(0.20m^3)}{(1.5mol)(8.314\frac{J}{mol\cdot K})} = 1530K$$

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

Ans. $\Delta E_{int} = \frac{3}{2}nR\Delta T = \frac{3}{2}(1.5\ mol)(8.314\frac{J}{mol\cdot K})(-910.\ K) = -1.70\times10^4 J$

d. How much heat is gained by the gas during this process?

Ans. $Q = 0\ J$ (adiabatic process!)

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

Ans. $W = -\Delta E_{int} = 1.70\times10^4 J$

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. $P_i = \frac{nRT}{V} = \frac{(5.0\text{mol})(8.314\,\frac{\text{J}}{\text{mol}\cdot\text{K}})(800\text{K})}{(0.10\text{m}^3)} = 3.33\times10^5\text{Pa}$

Boltzmann Constant: k = $1.38\text{x}10^{-23}$ J/K
Gas Constant: R = 8.314 $^{J}/_{mol\cdot K}$

b. What is the final pressure of the gas, after adiabatic expansion?

Ans. $P_f = \frac{nRT}{V} = \frac{(5.0\text{mol})(8.314\frac{J}{mol\cdot K})(500K)}{(0.20m^3)} = 1.04\times10^5 Pa$

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

Ans. $\Delta E_{int} = \frac{3}{2}nR\Delta T = \frac{3}{2}(5.0\text{ mol})(8.314\frac{J}{mol\cdot K})(-300.\text{ K}) = -1.87\times10^4 J$

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

Ans. $W = -\Delta E_{int} = 1.87\times10^4 J$

Boltzmann Constant: k = 1.38×10^{-23} J/K
Gas Constant: R = 8.314 $^J/_{mol\cdot K}$