CHEM 2011: Introduction to Thermodynamics **Homework 2: First Law of Thermodynamics**
February 5, 2023 Joe Tran

Conceptual Problems

Question 2.1.1. Two ideal gas systems undergo reversible expansion under different conditions starting from the same P and V. At the end of the expansion, the two systems have the same volume. The pressure in the system that has undergone adiabatic expansion is lower than the pressure in the system that has gone isothermal expansion. Explain this result without using equations.

Question 2.1.2. Describe how reversible and irreversible expansions differ by discussing the degree to which equilibrium is maintained between the system and the surroundings.

Question 2.1.3. A cup filled with water (the system) at 278 K is placed in a microwave oven, and the oven is turned on for one minute during which it begins to boil. Which of q, W, and ΔU are positive, negative, or zero?

Question 2.1.4. What is wrong with the following statement? "Burns caused by steam at 100°C can be more severe than those caused by water at 100°C because steam contains more heat than water." Rewrite the sentence to convey the same information in a correct way.

Question 2.1.5. An ideal gas is expanded reversibly and adiabatically. Decide which of q, W, ΔU and ΔH are positive, negative, or zero.

Question 2.1.6. An ideal gas is expanded reversibly and isothermally. Decide which of q, W, ΔU and ΔH are positive, negative, or zero.

Question 2.1.7. An ideal gas is expanded adiabatically into a vacuum. Decide which of q, W, ΔU, and ΔH are positive, negative, or zero.

Question 2.1.8. A dishwasher is opened immediately before the drying cycle starts. Both ceramic mugs and plastic storage containers are beaded with water. After five minutes, the water beads on the mugs are gone and those on the plastic container are still there. Explain.

Question 2.1.9. Liquid water one degree above its freezing point is put into a glass bottle, and a rubber stopper is put into the neck. The bottle is put into a freezer, and after equilibrium is reached, ice has formed and the bottle has broken. Determine the signs of q, W, and ΔU for the process if the water is the system and everything else is in the surroundings.

Numerical Problems

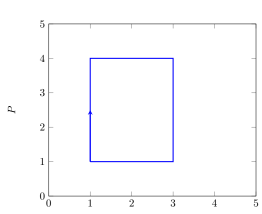
Question 2.2.1. A piston and cylinder assembly with a piston radius of 0.250 m contains 12.5 mol of an ideal gas with $C_{V,m} = \frac{3R}{2}$ at 298 K. The assembly is surrounded by air at a pressure of 1.00 bar. The cylindrical axis is vertical and the piston is oriented upward. The system is at equilibrium when the length of the cylinder is filled with gas is 0.750 m.

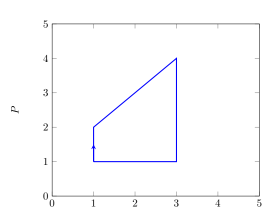
(a) Calculate the mass of the piston.

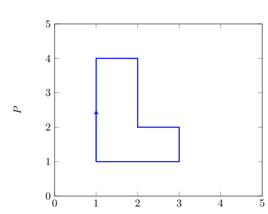
(b) Calculate the distance the piston moves if the temperature of the gas is increased to 750 K.

(c) Calculate the work done by the piston and cylinder assembly on the surroundings.

Question 2.2.2. By evaluating the integral $W = -\int P_{ext} dV$, calculate the work done in each of the cycles shown below in units of Joules. Assume all closed curves are oriented once in the clockwise direction.

(a) 

(b) 

(c) 

Question 2.2.3. As the volume of an ideal gas confined in a piston and cylinder assembly increases, 78.3 J of heat is absorbed from the surroundings. The external pressure is 1.00 bar, and the final volume of the gas is 65.6 L. If the ΔU for the process is -215 J, calculate the initial volume of the gas. Assume ideal gas behavior.

Question 2.2.4. 2.25 mol of an ideal gas at 32.0°C expands isothermally from an initial volume of 19.0 dm^3 to a final volume of 60.8 dm^3. Calculate W for this process for

(a) Expansion against a constant external pressure of 9.39×10^4 Pa.

(b) A reversible expansion.

Question 2.2.5. Consider the isothermal expansion of 1.75 mol of an ideal gas at 375 K from an initial pressure of 15.0 bar to a final pressure of 1.50 bar. Describe the process that will result in the greatest amount of work being done by the system with $P_{ext} \geq 1.50$ and calculate W. Describe the process that will result in the least amount of work being done by the system with $P_{ext} \geq 1.50$ bar and calculate W. What is the least amount of work done without restrictions on the external pressure?

Question 2.2.6. An ideal gas described by $T_1 = 275$ K, $P_1 = 1.10$ bar and $V_1 = 10.0$ L is heated at constant volume until $P = 10.0$ bar. It then undergoes a reversible isothermal expansion until $P = 1.10$ bar. It is then restored to its original state by the extraction of heat at constant pressure. Depict this closed-cycle process in a PV-diagram. Calculate W for each step and for the total process. What values for W would you calculate if the cycle were traversed in the opposite direction?

Question 2.2.7. A hiker caught in a thunderstorm loses heat when her clothing becomes wet. She is packing emergency rations that if completely metabolized, will release 35 kJ of heat per gram of rations consumed. How many grams of ration must the hiker consume to avoid a reduction in body temperature of 3.0 K as a result of heat loss? Assume the heat capacity of the body equals that of water and that the mass of the hiker is 62 kg. State any additional assumptions.

Question 2.2.8. The heat capacity of a solid lead oxide is given by

$$C_{P,m} = 44.35 + 1.47 \times 10^{-3}\frac{T}{K} \text{ in units of J/mol K}$$

Calculate the change in enthalpy of 2.25 mol of $PbO_{(s)}$ if it is cooled from 790 K to 390 K at constant pressure.

Question 2.2.9. A vessel containing 2.00 mol of an ideal gas with $P_1 = 1.00$ bar and $C_{P,m} = \frac{5R}{2}$ is in thermal contact with a water bath. Treat the vessel, gas, and water bath as being in thermal equilibrium, initially at 310 K, and separated by adiabatic walls from the rest of the universe. The vessel, gas, and water bath have an average heat capacity of $C_P = 2800$ J/K. The gas is compressed reversibly to $P_2 = 15.0$ bar. What is the temperature of the system after thermal equilibrium has been established?

Question 2.2.10. 1.75 moles of an ideal gas, for which $C_{V,m} = \frac{3R}{2}$ is subjected to two successive changes in state:

(1) From 15.0°C and 125×10^3 Pa, the gas expanded isothermally against a constant pressure of 15.2×10^3 Pa to twice the initial volume.

(2) At the end of the previous process, the gas is cooled at constant volume from 15.0° to -35.0°C.

Calculate q, W, ΔU and ΔH for each of the stages. Also calculate q, W, ΔH and ΔH for the complete process.

Question 2.2.11. A 1.75 mol sample of an ideal gas for which $C_{V,m} = \frac{3R}{2}$ undergoes the following two-step process:

(1) From an initial state of the ideal gas described by $T = 15.0$°C and $P = 5.00 \times 10^4$ Pa, the gas undergoes an isothermal expansion against a constant external pressure of 2.50×10^4 Pa until the volume has doubled.

(2) Subsequently, the gas is cooled at constant volume. The temperature falls to -19.0°C.

Calculate q, W, ΔU and ΔH in each step and for the overall process.

Question 2.2.12. The temperature of 2.75 mol of an ideal gas is changed from 95.0°C to 15.0°C at constant pressure. $C_{V,m} = \frac{3R}{2}$. Calculate q, W, ΔU and ΔH.

Question 2.2.13. A pellet of Zn of mass 25.0 g is dropped into a flask containing dilute H_2SO_4 at a pressure of $P = 1.00$ bar and a temperature of $T = 310$ K. What reaction occurs? Calculate W for the process.

Question 2.2.14. Calculate q, W, ΔU and ΔH if 1.50 mol of an ideal gas with $C_{V,m} = \frac{3R}{2}$ undergoes a reversible adiabatic expansion from an initial volume $V_1 = 19.0$ dm^3 to a final volume $V_2 = 60.8$ dm^3. The initial temperature is 32.0°C.

Question 2.2.15. A bottle at 300 K contains an ideal gas at a pressure of 145×10^3 Pa. The rubber stopper closing the bottle is removed. The gas expands adiabatically against $P_{ext} = 1.00 \times 10^5$ Pa, and some gas is expelled from the bottle in the process. When $P = P_{ext}$, the stopper is quickly replaced. The gas remaining in the bottle slowly warms up to 300 K. What is the final pressure in the bottle for a monatomic gas, for which $C_{V,m} = \frac{3R}{2}$ and a diatomic gas for $C_{V,m} = \frac{5R}{2}$?

Question 2.2.16. A 2.50 mol sample of an ideal gas for which $P = 3.25$ bar and $T = 298$ K is expanded adiabatically against an external pressure of 0.225 bar until the final pressure is 0.225 bar. Calculate the final pressure q, W, ΔH and ΔU for

(a) $C_{V,m} = \frac{3R}{2}$

(b) $C_{V,m} = \frac{5R}{2}$

Question 2.2.17. Consider the adiabatic expansion of an ideal monatomic gas with $C_{V,m} = \frac{3R}{2}$. The initial state is described by $P = 9.50$ bar and $T = 273$ K.

(a) Calculate the final temperature if the gas undergoes a reversible adiabatic expansion to a final pressure of $P = 1.25$ bar.

(b) Calculate the final temperature if the same gas undergoes an adiabatic expansion against an external pressure of $P = 1.25$ bar to a final pressure of $P = 1.25$ bar.

Question 2.2.18. 2.75 mol of an ideal gas is expanded from 375 K and an initial pressure of 4.50 bar to a final pressure of 1.00 bar, and $C_{P,m} = \frac{5R}{2}$. Calculate W for the following two cases:

(a) The expansion is isothermal and reversible.

(b) The expansion is adiabatic and reversible.

Question 2.2.19. A 1.75 mol sample of CO_2 for which $C_{P,m} = 37.1$ J/mol K at 298 K is expanded reversible and adiabatically from a volume of 3.25 L and a temperature of 298 K to a final volume of 40.0 L. Calculate the final temperature, q, W, ΔH, and ΔU. Assume that $C_{P,m}$ is constant over the temperature interval.