2.6 EXERCISES

Thermodynamic Processes

Ex 2.6.1. Draw three isobaric processes for one mole of an ideal gas in the (p, V), (V, T) and (p, T) planes. For concreteness, you can assume the isobaric processes to have pressures $p_1 = 1$ atm, $p_2 = 2$ atm, and $p_3 = 3$ atm.

Ex 2.6.2. The van der Waals coefficients for oxygen are $a = 0.138$ J.m^3/mol^2 and b=3.18 $\times$ 10^{-5} m^3/mol. Use these values to draw isotherms of oxygen at 100 K, 200 K and 300 K. On the same graph draw isotherms of an ideal gas. Compare the two.

Work

Ex 2.6.3. Find the work done in the quasi-static processes shown in the diagrams in Fig. 2.18. The states are given as (p, V) values for the points in the pV plane: $1(3\text{ atm}, 4\text{ L})$, $2(3\text{ atm}, 6\text{ L})$, $3(5\text{ atm}, 4\text{ L})$, $4(2\text{ atm}, 6\text{ L})$, $5(4\text{ atm}, 2\text{ L})$, $6(5\text{ atm}, 5\text{ L})$, $7(2\text{ atm}, 5\text{ L})$. (Note: 1 L = 10^{-3}m^3).

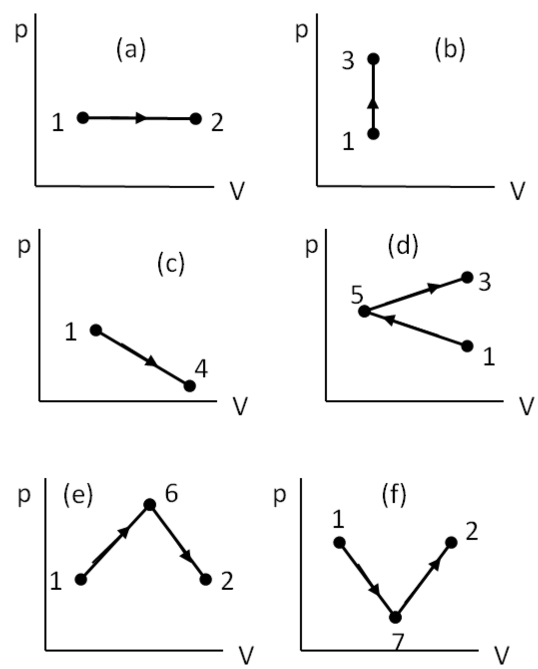


Figure 2.18: Exercise 2.6.3.

Ex 2.6.4. In an adiabatic process oxygen gas in a container is compressed along a path that can be described by the following pressure in atm as a function of volume V, with $V_0 = 1$ L.

$$p = (3.0\text{ atm})\,(V/V_0)^{-1.2}.$$

The initial and final volumes during the process were 2 L and 1.5 L respectively. Find the amount of work done on the gas.

Ex 2.6.5. A cylinder containing three moles of a monatomic ideal gas is heated at a constant pressure of 2 atm. The temperature of the gas changes from 300 K to 350 K as a result of the expansion. Find work done (a) on the gas, and (b) by the gas.

Ex 2.6.6. A cylinder containing three moles of nitrogen gas is heated at a constant pressure of 2 atm. The temperature of the gas changes from 300 K to 350 K as a result of the expansion. Find work done (a) on the gas, and (b) by the gas by using van der Waals equation of state instead of ideal gas law.

Ex 2.6.7. A 1500-kg block of solid copper is compressed quasi-statically at a constant temperature of 20°C from a pressure of 100 kPa to 1,500,000 kPa. Given the density of copper to be 8930 kg/m^3, the isothermal compressibility k to be 7.16×10^{-12} Pa^{-1}, find the amount of work done by the copper block.

Ex 2.6.8. A concrete container has 1.5×10^{-3} m^3 of water at 20°C at 1 atmosphere of pressure. The pressure is increased to 1.2 MPa. Find the amount of work done by water assuming no change in the concrete container and constant temperature. Use isothermal compressibility of water at 20°C to be 4.6×10^{-4} MPa^{-1}.

First Law and Specific Heat of Ideal Gas

Ex 2.6.9. Consider the processes shown in Fig. 2.19. In the process ab and bc, 3600 J and 2400 J of heat are added to the system. (a) Find the work done in each of the processes ab, bc, ad and dc. (b) Find the internal energy change in processes ab and bc. (c) Find the internal energy difference between states c and a. (d) Find the total heat added in the adc process. (e) From the information give, can you find the heat added in process ad? Why or why not?

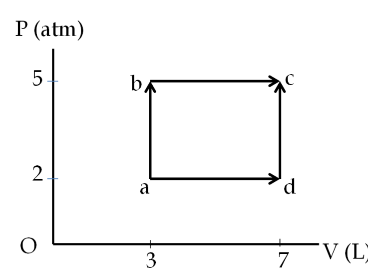
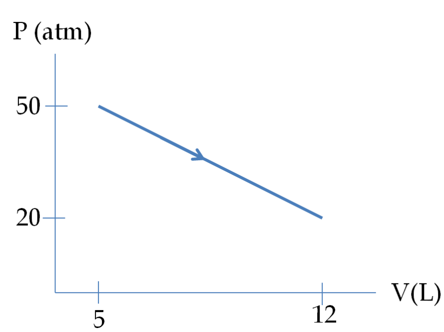


Figure 2.19: Exercise 2.6.9.

Ex 2.6.10. Consider the process for steam in a cylinder shown in the figure. Suppose the change in the internal energy in this process is 30 kJ. Find the heat entering the system.



Ex 2.6.11. The state of 30 moles of steam in a cylinder is changed in a cyclic manner from a-b-c-a, where the pressure and volume of the states are: a(30 atm, 20 L), b(50 atm, 20 L), and c(50 atm, 45 L). Assume each change takes place along the line connecting the initial and final states in the pV plane. (a) Display the cycle in the pV plane. (b) Find the net work done by the steam in one cycle. (c) Find the net amount of heat flow in the steam over the course of one cycle.

Specific Heat and Calorimetry

Ex 2.6.12. How much heat is needed to melt 10 kg of copper that is initially at 25°C? Melting point of copper = 1083°C; heat of melting of copper = 4913 J/kg; Specific heat of copper = 390 J per kg per deg C.

Ex 2.6.13. A cube of ice from a freezer at -10°C is placed in an insulated 5 kg brass jar which is initially at 60°C. After sometime has elapsed and the equilibrium has reached, it is found that the brass jar contains water at $+10$°C and no ice. Find the mass of the ice initially. Use specific heat of brass = 380 J per kg per deg C, specific heat of ice = 2000 J per kg per deg C.

Ex 2.6.14. In an insulated aluminum container of mass 40 kg, there is 20 kg of ice at -12.5°C. 100 g of superheated steam at 120°C is introduced in the container. What is the final state, i.e. the final temperature and amounts of ice, water and steam in the final state?

Ex 2.6.15. During an aerobic exercise a person of mass 60 kg produces 250 kcal energy per hour from her metabolic rate. Suppose 25% of this energy goes into aerobic workout and the rest is converted into heat which is used to evaporate the sweat. Assume the heat of evaporation at the body temperature of 37°C to be approximately 2.4×10^6 J/kg. What is the rate at which water is lost from the body?

Ex 2.6.16. A wire of resistance 2 Ohms is wound around a copper cylinder of mass 200 g. The arrangement is insulated so that all heat generated when a current is passed in the wire goes to raise the temperature of the wire and copper. A 5-A current is passed through the wire for 10 sec. It is found that the temperature of copper rises by 6.5°C. The experiment is done at atmospheric pressure. (a) What value of specific heat of copper does this experiment yield? (b) What would be molar specific heat of copper based on the data of this experiment? (c) What is the heat capacity of the copper cylinder? Ignore the effect of the heating of the current-carrying wire itself.

Use: Energy given to the wire of resistance R by current I over time Δt equals $I^2 R\Delta t$.

Joule Thompson effect, Enthalpy, Adiabatic expansion

Joule Thompson effect

Ex 2.6.17. The internal energy of n moles of a monatomic ideal gas at temperature T degrees Kelvin is given by the following formula, $U = \frac{3}{2}nRT$. What is its enthalpy in terms of the temperature?

Ex 2.6.18. In a throttling process, 2.5 moles of Argon is expanded from a high pressure 30 atm and volume 2 L to 1 atm and volume 70 L. (a) What is the change in the internal energy? (b) Interpret your answer and determine whether the gas will cool off or heat up.

Ex 2.6.19. In a throttling process 1.4 mol of the Helium gas is to be cooled from 20°C to 10°C by expanding from a 40 atm to 1 atm. (a) What would be the corresponding volume change? (b) What is the change in the internal energy?

Enthalpy

Ex 2.6.20. One liter of water in a beaker is heated from 25°C to 30°C at constant pressure of 1 atm. Find the change in enthalpy of water.

Ex 2.6.21. Five moles of a monatomic ideal gas in a cylinder at 27°C is expanded isothermally from a volume of 5 L to 10 L. (a) What are the changes in its internal energy and enthalpy? (b) How much work was done on the gas in the process? (c) How much heat was transferred to the gas?

Ex 2.6.22. Four moles of a monatomic ideal gas in a cylinder at 27°C is expanded at constant pressure equal to 1 atm till its volume doubles. (a) What are the changes in its internal energy and enthalpy? (b) How much work was done by the gas in the process? (c) How much heat was transferred to the gas?

Ex 2.6.23. Two moles of Helium gas is expanded at a constant pressure of 5 atm. The initial temperature was 20°C. It was found that the internal energy changed by 24 J. Find the change in the enthalpy of the gas.

Quasi-static adiabatic expansion

Ex 2.6.24. (a) An ideal gas expands adiabatically from a volume of 2×10^{-3} m^3 to 2.5×10^{-3} m^3. If the initial pressure and temperature were 5.0×10^5 Pa and 300 K respectively, what are the final pressure and temperature of the gas? Use $\gamma = 5/3$ for the gas. (b) In an isothermal process, an ideal gas expands from a volume of 2×10^{-3} m^3 to 2.5×10^{-3} m^3. If the initial pressure and temperature were 5.0×10^5 Pa and 300 K respectively, what are the final pressure and temperature of the gas?

Ex 2.6.25. On an adiabatic process of an ideal gas pressure, volume and temperature change such that pV^γ is constant with $\gamma = 5/3$ for monatomic gas such as helium and $\gamma = 7/5$ for diatomic gas such as hydrogen at room temperature. Use numerical values to plot two isotherms of 1 mole of helium gas using ideal gas law and two adiabatic processes mediating between them. Use $T_1 = 500$ K, $V_1 = 1$ L, and $T_2 = 300$ K for your plot.

Ex 2.6.26. Two moles of a monatomic ideal gas such as Helium is compressed adiabatically and reversibly from a state (3 atm, 5 L) to a state with pressure 4 atm. (a) Find the volume and temperature of the final state. (b) Find the temperature of the initial state of the gas. (c) Find the work done by the gas in the process. (d) Find the change in internal energy of the gas in the process.

Ex 2.6.27. Two moles of a monatomic ideal gas such as oxygen is compressed adiabatically and reversibly from a state (3 atm, 5 L) to a state with a pressure of 4 atm. (a) Find the volume and temperature of the final state. (b) Find the temperature of the initial state. (c) Find work done by the gas in the process. (d) Find the change in internal energy in the process. Assume $C_V = \frac{5}{2}R$ and $C_p = C_V + R$ for the diatomic ideal gas in the conditions given.

Ex 2.6.28. An insulated vessel contains 1.5 moles of Argon at 2 atm. The gas initially occupies a volume of 5 L. As a result of the adiabatic expansion the pressure of the gas is reduced to 1 atm. (a) Find the volume and temperature of the final state. (b) Find the temperature of the gas in the initial state. (c) Find the work done by the gas in the process. (d) Find the change in the internal energy of the gas in the process.