Solution

$$\ln\left(\frac{T_f}{T_i}\right) = -(\gamma - 1)\ln\left(\frac{V_f}{V_i}\right)$$

$$= -(\gamma - 1)\ln\left(\frac{T_f P_i}{T_i P_f}\right) = -(\gamma - 1)\ln\left(\frac{T_f}{T_i}\right) - (\gamma - 1)\ln\left(\frac{P_i}{P_f}\right)$$

$$= -\frac{(\gamma - 1)}{\gamma}\ln\left(\frac{P_i}{P_f}\right) = -\frac{\left(\dfrac{C_{P,m}}{C_{P,m} - R} - 1\right)}{\dfrac{C_{P,m}}{C_{P,m} - R}}\ln\left(\frac{P_i}{P_f}\right)$$

$$= -\frac{\left(\dfrac{28.86\ \mathrm{J\,K^{-1}mol^{-1}}}{28.86\ \mathrm{J\,K^{-1}mol^{-1}} - 8.314\ \mathrm{J\,K^{-1}mol^{-1}}} - 1\right)}{\dfrac{28.86\ \mathrm{J\,K^{-1}mol^{-1}}}{28.86\ \mathrm{J\,K^{-1}mol^{-1}} - 8.314\ \mathrm{J\,K^{-1}mol^{-1}}}} \times \ln\left(\frac{0.802\ \mathrm{atm}}{0.602\ \mathrm{atm}}\right)$$

$$= -0.0826$$

$$T_f = 0.9207T_i = 265\ \mathrm{K}$$

You can expect snow.

Vocabulary

cyclic path
enthalpy
exact differential
first law of thermodynamics
heat
heat capacity
indicator diagram
internal energy
irreversible process
isobaric
isochoric
isothermal
isothermal process
path
path function
quasi-static process
reversible process
state function
work

Questions on Concepts

Q2.1 Electrical current is passed through a resistor immersed in a liquid in an adiabatic container. The temperature of the liquid is varied by 1°C. The system consists solely of the liquid. Does heat or work flow across the boundary between the system and surroundings? Justify your answer.

Q2.2 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 in the system that has undergone isothermal expansion. Explain this result without using equations.

Q2.3 You have a liquid and its gaseous form in equilibrium in a piston and cylinder assembly in a constant temperature bath. Give an example of a reversible process.

Q2.4 Describe how reversible and irreversible expansions differ by discussing the degree to which equilibrium is maintained between the system and the surroundings.

Q2.5 For a constant pressure process, $\Delta H = q_P$. Does it follow that q is a state function? Explain.

Q2.6 A cup of water at 278 K (the system) is placed in a microwave oven and the oven is turned on for 1 minute during which it begins to boil. Which of q, w, and ΔU are positive, negative, or zero?

Q2.7 In the experiment shown in Figure 2.4a, $\Delta U_{\mathrm{II}} < 0$, but $\Delta T_{\mathrm{II}} > 0$. Explain how this is possible.

Q2.8 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 correctly.

Q2.9 Why is it incorrect to speak of the heat or work associated with a system?

Q2.10 You have a liquid and its gaseous form in equilibrium in a piston and cylinder assembly in a constant temperature bath. Give an example of an irreversible process.

Q2.11 What is wrong with the following statement? *Because the well-insulated house stored a lot of heat, the temperature didn't fall much when the furnace failed.* Rewrite the sentence to convey the same information correctly.

Q2.12 Explain how a mass of water in the surroundings can be used to determine q for a process. Calculate q if the temperature of a 1.00-kg water bath in the surroundings increases by 1.25°C. Assume that the surroundings are at a constant pressure.

Q2.13 A chemical reaction occurs in a constant volume enclosure separated from the surroundings by diathermal walls. Can you say whether the temperature of the surroundings increases, decreases, or remains the same in this process? Explain.

Q2.14 Explain the relationship between the terms *exact differential* and *state function*.

Q2.15 In the experiment shown in Figure 2.4b, the weight drops in a very short time. How will the temperature of the water change with time?

Problems

Problem numbers in **red** indicate that the solution to the problem is given in the *Student's Solutions Manual.*

P2.1 4.25 moles of an ideal gas with $C_{V,m} = 3R/2$ initially at a temperature $T_i = 325$ K and $P_i = 1.00$ bar is enclosed in an adiabatic piston and cylinder assembly. The gas is compressed by placing a 575-kg mass on the piston of diameter 20.0 cm. Calculate the work done in this process and the distance that the piston travels. Assume that the mass of the piston is negligible.

P2.2 The temperature of 2.50 moles of an ideal gas increases from 13.5° to 55.1°C as the gas is compressed adiabatically. Calculate q, w, ΔU, and ΔH for this process assuming that $C_{V,m} = 3R/2$.

P2.3 1.65 moles of an ideal gas, for which $C_{V,m} = 3R/2$, is subjected to two successive changes in state: (1) From 39.0°C and $100. \times 10^3$ Pa, the gas is expanded isothermally against a constant pressure of 16.5×10^3 Pa to twice the initial volume. (2) At the end of the previous process, the gas is cooled at constant volume from 39.0°C to –25.0°C. Calculate q, w, ΔU, and ΔH for each of the stages. Also calculate q, w, ΔU, and ΔH for the complete process.

P2.4 A hiker caught in a thunderstorm loses heat when her clothing becomes wet. She is packing emergency rations which if completely metabolized will release 30. kJ of heat per gram of rations consumed. How much rations must the hiker consume to avoid a reduction in body temperature of 4.0 K as a result of heat loss? Assume the heat capacity of the body equals that of water and that the hiker weighs 55 kg. State any additional assumptions.

P2.5 Count Rumford observed that using cannon boring machinery a single horse could heat 11.6 kg of cold water at $T = 273$ K to $T = 355$ K in 2.5 hours. Assuming the same rate of work, how high could a horse raise a 150. kg weight in 1 minute?

P2.6 2.25 moles of an ideal gas at 35.6°C expands isothermally from an initial volume of 26.0 $\mathrm{dm^3}$ to a final volume of 70.0 $\mathrm{dm^3}$. Calculate w for this process (a) for expansion against a constant external pressure of 1.00×10^5 Pa and (b) for a reversible expansion.

P2.7 Calculate q, w, ΔU, and ΔH if 1.65 mol of an ideal gas with $C_{V,m} = 3R/2$ undergoes a reversible adiabatic expansion from an initial volume $V_i = 7.75\ \mathrm{m^3}$ to a final volume $V_f = 20.5\ \mathrm{m^3}$. The initial temperature is 300. K.

P2.8 Calculate w for the adiabatic expansion of 1 mol of an ideal gas at an initial pressure of 2.25 bar from an initial temperature of 475 K to a final temperature of 322 K. Write an expression for the work done in the isothermal reversible expansion of the gas at 322 K from an initial pressure of 2.25 bar. What value of the final pressure would give the same value of w as the first part of this problem? Assume that $C_{P,m} = 5R/2$.

P2.9 At 298 K and 1 bar pressure, the density of water is 0.9970 g $\mathrm{cm^{-3}}$, and $C_{P,m} = 75.3\ \mathrm{J\,K^{-1}mol^{-1}}$. The change in volume with temperature is given by $\Delta V = V_{initial}\beta\Delta T$ where β, the coefficient of thermal expansion, is $2.07 \times 10^{-4}\ \mathrm{K^{-1}}$. If the temperature of 250. g of water is increased by 38.0 K, calculate w, q, ΔH, and ΔU.

P2.10 A muscle fiber contracts by 2.0 cm and in doing so lifts a weight. Calculate the work performed by the fiber. Assume the muscle fiber obeys Hooke's law $F = -k\,x$ with a force constant, k, of 800. N $\mathrm{m^{-1}}$.

P2.11 A cylindrical vessel with rigid adiabatic walls is separated into two parts by a frictionless adiabatic piston. Each part contains 50.0 L of an ideal monatomic gas with $C_{V,m} = 3R/2$. Initially, $T_i = 325$ K and $P_i = 2.50 \times 10^5$ Pa in each part. Heat is slowly introduced into the left part using an electrical heater until the piston has moved sufficiently to the right to result in a final pressure $P_f = 7.50$ bar in the right part. Consider the compression of the gas in the right part to be a reversible process.

a. Calculate the work done on the right part in this process and the final temperature in the right part.

b. Calculate the final temperature in the left part and the amount of heat that flowed into this part.

P2.12 In the reversible adiabatic expansion of 2.25 mol of an ideal gas from an initial temperature of 32.0°C, the work done on the surroundings is 1450. J. If $C_{V,m} = 3R/2$, calculate q, w, ΔU, and ΔH.