**P2.13** A system consisting of 73.2 g of liquid water at 289 K is heated using an immersion heater at a constant pressure of 1.00 bar. If a current of 2.25 A passes through the 10.0-ohm resistor for 125. s, what is the final temperature of the water?

**P2.14** 2.75 moles of an ideal gas is expanded from 375 K and an initial pressure of 4.75 bar to a final pressure of 1.00 bar, and $C_{P,m} = 5R/2$. Calculate $w$ for the following two cases:

a. The expansion is isothermal and reversible.

b. The expansion is adiabatic and reversible.

b. Without resorting to equations, explain why the result to part (b) is greater than or less than the result to part (a).

**P2.15** A bottle at 285 K contains an ideal gas at a pressure of $155.7 \times 10^3$ Pa. The rubber stopper closing the bottle is removed. The gas expands adiabatically against $P_{external} = 111.4 \times 10^3$ Pa, and some gas is expelled from the bottle in the process. When $P = P_{external}$, the stopper is quickly replaced. The gas remaining in the bottle slowly warms up to 285 K. What is the final pressure in the bottle for a monatomic gas, for which $C_{V,m} = 3R/2$, and a diatomic gas, for which $C_{V,m} = 5R/2$?

**P2.16** One mole of an ideal gas with $C_{V,m} = 3R/2$ initially at 325 K and $1.50 \times 10^5$ Pa undergoes a reversible adiabatic compression. At the end of the process, the pressure is $2.50 \times 10^6$ Pa. Calculate the final temperature of the gas. Calculate $q$, $w$, $\Delta U$, and $\Delta H$ for this process.

**P2.17** A vessel containing 2.25 mol of an ideal gas with $P_i = 1.00$ bar and $C_{P,m} = 5R/2$ is in thermal contact with a water bath. Treat the vessel, gas, and water bath as being in thermal equilibrium, initially at 312 K, and as separated by adiabatic walls from the rest of the universe. The vessel, gas, and water bath have an average heat capacity of $C_P = 6250.$ J K$^{-1}$. The gas is compressed reversibly to $P_f = 10.5$ bar. What is the temperature of the system after thermal equilibrium has been established?

**P2.18** An ideal gas undergoes an expansion from the initial state described by $P_i$, $V_i$, $T$ to a final state described by $P_f$, $V_f$, $T$ in (a) a process at the constant external pressure $P_f$ and (b) in a reversible process. Derive expressions for the largest mass that can be lifted through a height $h$ in the surroundings in these processes.

**P2.19** An ideal gas described by $T_i = 300.$ K, $P_i = 1.00$ bar, and $V_i = 10.0$ L is heated at constant volume until $P = 10.0$ bar. It then undergoes a reversible isothermal expansion until $P = 1.00$ bar. It is then restored to its original state by the extraction of heat at constant pressure. Depict this closed-cycle process in a $P$–$V$ 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?

**P2.20** In an adiabatic compression of one mole of an ideal gas with $C_{V,m} = 5R/2$, the temperature rises from 293 K to 325 K. Calculate $q$, $w$, $\Delta H$, and $\Delta U$.

**P2.21** The heat capacity of solid lead oxide is given by

$$C_{P,m} = 44.35 + 1.47 \times 10^{-3}\frac{T}{\text{K}} \text{ in units of J K}^{-1}\text{mol}^{-1}$$

Calculate the change in enthalpy of 3.25 mol of PbO($s$) if it is cooled from 750. to 300. K at constant pressure.

**P2.22** One mol of carbon dioxide, for which $C_{P,m} = 37.1$ J K$^{-1}$ mol$^{-1}$ at 298 K, is expanded reversibly and adiabatically from a volume of 2.85 L and temperature of 300. K to a final volume of 16.5 L. Calculate the final temperature, $q$, $w$, $\Delta H$, and $\Delta U$. Assume that $C_{P,m}$ is constant over the temperature interval.

**P2.23** One mole of an ideal gas for which $P = 1.00$ bar and $T = 300.$ K is expanded adiabatically against an external pressure of 0.100 bar until the final pressure is 0.100 bar. Calculate the final temperature, $q$, $w$, $\Delta H$, and $\Delta U$ for (a) $C_{V,m} = 3R/2$, and (b) $C_{V,m} = 5R/2$.

**P2.24** 2.25 moles of $N_2$ in a state defined by $T_i = 300.$ K and $V_i = 1.00$ L undergoes an isothermal reversible expansion until $V_f = 20.5$ L. Calculate $w$ assuming (a) that the gas is described by the ideal gas law and (b) that the gas is described by the van der Waals equation of state. What is the percent error in using the ideal gas law instead of the van der Waals equation? The van der Waals parameters for $N_2$ are listed in Table 7.4.

**P2.25** A major league pitcher throws a baseball with a speed of 150. kilometers per hour. If the baseball weighs 220. grams and its heat capacity is 2.0 J g$^{-1}$ K$^{-1}$, calculate the temperature rise of the ball when it is stopped by the catcher's mitt. Assume no heat is transferred to the catcher's mitt and that the catcher's arm does not recoil when he/she catches the ball.

**P2.26** A 1.65-mol sample of an ideal gas for which $C_{V,m} = 3R/2$ undergoes the following two-step process: (1) From an initial state of the gas described by $T = 14.5$°C and $P = 2.00 \times 10^4$ Pa, the gas undergoes an isothermal expansion against a constant external pressure of $1.00 \times 10^4$ Pa until the volume has doubled. (2) Subsequently, the gas is cooled at constant volume. The temperature falls to –35.6°C. Calculate $q$, $w$, $\Delta U$, and $\Delta H$ for each step and for the overall process.

**P2.27** 1.75 moles of an ideal gas, for which $C_{V,m} = 3R/2$, initially at 32.0°C and $2.50 \times 10^6$ Pa undergoes a two-stage transformation. For each of the stages described in the following list, calculate the final pressure, as well as $q$, $w$, $\Delta U$, and $\Delta H$. Also calculate $q$, $w$, $\Delta U$, and $\Delta H$ for the complete process.

a. The gas is expanded isothermally and reversibly until the volume doubles.

b. Beginning at the end of the first stage, the temperature is raised to 92.0°C at constant volume.

**P2.28** 1.75 mole of an ideal gas with $C_{V,m} = 3R/2$ is expanded adiabatically against a constant external pressure of 1.00 bar. The initial temperature and pressure are $T_i = 290.$ K and $P_i = 19.5$ bar. The final pressure is $P_f = 1.00$ bar. Calculate $q$, $w$, $\Delta U$, and $\Delta H$ for the process.



**P2.29** A nearly flat bicycle tire becomes noticeably warmer after it has been pumped up. Approximate this process as a reversible adiabatic compression. Assume the initial pressure and temperature of the air before it is put in the tire to be $P_i = 1.00$ bar and $T_i = 305$ K. The final pressure in the tire is $P_f = 5.75$ bar. Calculate the final temperature of the air in the tire. Assume that $C_{V,m} = 5R/2$.

**P2.30** For 2.25 mol of an ideal gas, $P_{external} = P = 200. \times 10^3$ Pa. The temperature is changed from 122°C to 28.5°C, and $C_{V,m} = 3R/2$. Calculate $q$, $w$, $\Delta U$, and $\Delta H$.

**P2.31** Suppose an adult is encased in a thermally insulating barrier so that all the heat evolved by metabolism of foodstuffs is retained by the body. What temperature does her body reach after 3.0 hours? Assume the heat capacity of the body is 4.18 J g$^{-1}$ K$^{-1}$ and that the heat produced by metabolism is 10. kJ kg$^{-1}$ hr$^{-1}$.

**P2.32** Consider the isothermal expansion of 4.50 mol of an ideal gas at 450. K from an initial pressure of 12.0 bar to a final pressure of 2.75 bar. Describe the process that will result in the greatest amount of work being done by the system and calculate $w$. Describe the process that will result in the least amount of work being done by the system with a constant external pressure and calculate $w$. What is the least amount of work done without restrictions on the external pressure?

**P2.33** An automobile tire contains air at $275. \times 10^3$ Pa at 27.5°C. The stem valve is removed and the air is allowed to expand adiabatically against the constant external pressure of one bar until $P = P_{external}$. For air, $C_{V,m} = 5R/2$. Calculate the final temperature. Assume ideal gas behavior.

**P2.34** One mole of an ideal gas is subjected to the changes below. Calculate the change in temperature for each case if $C_{V,m} = 3R/2$.

- $q = -500$ J, $w = 150$ J
- $q = 425.$ J, $w = -425$ J
- $q = 0$, $w = 175$ J

**P2.35** Consider the adiabatic expansion of 0.500 mol of an ideal monatomic gas with $C_{V,m} = 3R/2$. The initial state is described by $P = 5.50$ bar and $T = 285.$ K.

a. Calculate the final temperature if the gas undergoes a reversible adiabatic expansion to a final pressure of $P = 1.00$ bar.

b. Calculate the final temperature if the same gas undergoes an adiabatic expansion against an external pressure of $P = 1.00$ bar to a final pressure $P = 1.00$ bar.

c. Explain the difference in your results for parts (a) and (b).

**P2.36** A pellet of Zn of mass 14.5 g is dropped into a flask containing dilute $H_2SO_4$ at a pressure of $P = 1.00$ bar and temperature of $T = 325$ K. What is the reaction that occurs? Calculate $w$ for the process.

**P2.37** Calculate $\Delta H$ and $\Delta U$ for the transformation of 1 mol of an ideal gas from 35.0°C and 1.00 atm to 422°C and 17.0 atm if

$$C_{P,m} = 20.9 + 0.042\frac{T}{\text{K}} \text{ in units of J K}^{-1}\text{ mol}^{-1}$$

**P2.38** 2.50 moles of an ideal gas for which $C_{V,m} = 20.8$ J K$^{-1}$ mol$^{-1}$ is heated from an initial temperature of 10.5°C to a final temperature of 305°C at constant volume. Calculate $q$, $w$, $\Delta U$, and $\Delta H$ for this process.

**P2.39** An ideal gas undergoes a single-stage expansion against a constant external pressure $P_{external} = P_f$ at constant temperature from $T$, $P_i$, $V_i$, to $T$, $P_f$, $V_f$.

a. What is the largest mass $m$ that can be lifted through the height $h$ in this expansion?

b. The system is restored to its initial state in a single-state compression. What is the smallest mass $m'$ that must fall through the height $h$ to restore the system to its initial state?

c. If $h = 10.0$ cm, $P_i = 2.50 \times 10^6$ Pa, $P_f = 0.750 \times 10^6$ Pa, $T = 300.$ K, and $n = 1.50$ mol, calculate the values of the masses in parts (a) and (b).

**P2.40** The formalism of the Young's modulus is sometimes used to calculate the reversible work involved in extending or compressing an elastic material. Assume a force $F$ is applied to an elastic rod of cross sectional area $A_0$ and length $L_0$. As a result of this force the rod changes in length by $\Delta L$. The Young's modulus $E$ is defined as

$$E = \frac{\text{tensile stress}}{\text{tensile strain}} = \frac{\dfrac{F}{A_0}}{\dfrac{\Delta L}{L_0}} = \frac{FL_0}{A_0 \Delta L}$$

a. Relate $k$ in Hooke's Law to the Young's modulus expression given above.

b. Using your result in part (a) show that the magnitude of the reversible work involved in changing the length $L_0$ of an elastic cylinder of cross sectional area $A_0$ by $\Delta L$ is

$$w = \frac{1}{2}\left(\frac{\Delta L}{L_0}\right)^2 EA_0L_0.$$

**P2.41** The Young's modulus (see P2.40) of muscle fiber is approximately $3.12 \times 10^7$ Pa. A muscle fiber 2.00 cm in length and 0.100 cm in diameter is suspended with a mass $M$ hanging at its end. Calculate the mass required to extend the length of the fiber by 10%.

**P2.42** DNA can be modeled as an elastic rod which can be twisted or bent. Suppose a DNA molecule of length $L$ is bent such that it lies on the arc of a circle of radius $R_c$. The reversible work involved in bending DNA without twisting is $w_{bend} = BL/2R_c^2$ where $B$ is the bending force constant. The DNA in a nucleosome particle is about 680. Å in length. Nucleosomal DNA is bent around a protein complex called the histone octamer into a circle of radius 55 Å. Calculate the reversible work involved in bending the DNA around the histone octamer if the force constant $B = 2.00 \times 10^{-28}$ J m.

**P2.43** 3.00 moles of an ideal gas are compressed isothermally from 56.0 to 24.0 L using a constant external pressure of 3.35 atm. Calculate $q$, $w$, $\Delta U$, and $\Delta H$.