and

$$\left. \begin{array}{l} T_{R_2} = \dfrac{T_2}{T_{\text{cr}}} = \dfrac{300\text{ K}}{154.8\text{ K}} = 1.94 \\[3mm] P_{R_2} = \dfrac{P_2}{P_{\text{cr}}} = \dfrac{10\text{ MPa}}{5.08\text{ MPa}} = 1.97 \end{array} \right\} Z_{h_2} = 0.48,\ Z_{s_2} = 0.20$$

Then the enthalpy and entropy changes of oxygen during this process are determined by substituting the values above into Eqs. 12–58 and 12–63,

$$\bar{h}_2 - \bar{h}_1 = (\bar{h}_2 - \bar{h}_1)_{\text{ideal}} - R_u T_{\text{cr}}(Z_{h_2} - Z_{h_1})$$

$$= 2332\text{ kJ/kmol} - (8.314\text{ kJ/kmol} \cdot \text{K})\big[154.8\text{ K}(0.48 - 0.53)\big]$$

$$= \mathbf{2396\ kJ/kmol}$$

and

$$\bar{s}_2 - \bar{s}_1 = (\bar{s}_2 - \bar{s}_1)_{\text{ideal}} - R_u(Z_{s_2} - Z_{s_1})$$

$$= 3.28\text{ kJ/kmol} \cdot \text{K} - (8.314\text{ kJ/kmol} \cdot \text{K})(0.20 - 0.25)$$

$$= \mathbf{3.70\ kJ/kmol \cdot K}$$

Discussion Note that the ideal-gas assumption would underestimate the enthalpy change of the oxygen by 2.7 percent and the entropy change by 11.4 percent.

SUMMARY

Some thermodynamic properties can be measured directly, but many others cannot. Therefore, it is necessary to develop some relations between these two groups so that the properties that cannot be measured directly can be evaluated. The derivations are based on the fact that properties are point functions, and the state of a simple, compressible system is completely specified by any two independent, intensive properties.

The equations that relate the partial derivatives of properties P, v, T, and s of a simple compressible substance to each other are called the *Maxwell relations*. They are obtained from the *four Gibbs equations*, expressed as

$$du = T\,ds - P\,dv$$
$$dh = T\,ds + v\,dP$$
$$da = -s\,dT - P\,dv$$
$$dg = -s\,dT + v\,dP$$

The *Maxwell relations* are

$$\left(\frac{\partial T}{\partial v}\right)_s = -\left(\frac{\partial P}{\partial s}\right)_v$$

$$\left(\frac{\partial T}{\partial P}\right)_s = \left(\frac{\partial v}{\partial s}\right)_P$$

$$\left(\frac{\partial s}{\partial v}\right)_T = \left(\frac{\partial P}{\partial T}\right)_v$$

$$\left(\frac{\partial s}{\partial P}\right)_T = -\left(\frac{\partial v}{\partial T}\right)_P$$

The *Clapeyron equation* enables us to determine the enthalpy change associated with a phase change from a knowledge of P, v, and T data alone. It is expressed as

$$\left(\frac{dP}{dT}\right)_{\text{sat}} = \frac{h_{fg}}{T v_{fg}}$$

For liquid–vapor and solid–vapor phase-change processes at low pressures, it can be approximated as

$$\ln\left(\frac{P_2}{P_1}\right)_{\text{sat}} \cong \frac{h_{fg}}{R}\left(\frac{T_2 - T_1}{T_1 T_2}\right)_{\text{sat}}$$

The changes in internal energy, enthalpy, and entropy of a simple compressible substance can be expressed in terms of pressure, specific volume, temperature, and specific heats alone as

$$du = c_v\, dT + \left[T\left(\frac{\partial P}{\partial T}\right)_v - P\right]dv$$

$$dh = c_p\, dT + \left[v - T\left(\frac{\partial v}{\partial T}\right)_P\right]dP$$

$$ds = \frac{c_v}{T}\, dT + \left(\frac{\partial P}{\partial T}\right)_v dv$$

or

$$ds = \frac{c_p}{T}\, dT - \left(\frac{\partial v}{\partial T}\right)_P dP$$

For specific heats, we have the following general relations:

$$\left(\frac{\partial c_v}{\partial v}\right)_T = T\left(\frac{\partial^2 P}{\partial T^2}\right)_v$$

$$\left(\frac{\partial c_p}{\partial P}\right)_T = -T\left(\frac{\partial^2 v}{\partial T^2}\right)_P$$

$$c_{p,T} - c_{p0,T} = -T\int_0^P \left(\frac{\partial^2 v}{\partial T^2}\right)_P dP$$

$$c_p - c_v = -T\left(\frac{\partial v}{\partial T}\right)_P^2 \left(\frac{\partial P}{\partial v}\right)_T$$

$$c_p - c_v = \frac{vT\beta^2}{\alpha}$$

where β is the *volume expansivity* and α is the *isothermal compressibility*, defined as

$$\beta = \frac{1}{v}\left(\frac{\partial v}{\partial T}\right)_P \quad \text{and} \quad \alpha = -\frac{1}{v}\left(\frac{\partial v}{\partial P}\right)_T$$

The difference $c_p - c_v$ is equal to R for ideal gases and to zero for incompressible substances.

The temperature behavior of a fluid during a throttling ($h = $ constant) process is described by the *Joule-Thomson coefficient*, defined as

$$\mu_{\text{JT}} = \left(\frac{\partial T}{\partial P}\right)_h$$

The Joule-Thomson coefficient is a measure of the change in temperature of a substance with pressure during a constant-enthalpy process, and it can also be expressed as

$$\mu_{\text{JT}} = -\frac{1}{c_p}\left[v - T\left(\frac{\partial v}{\partial T}\right)_P\right]$$

The enthalpy, internal energy, and entropy changes of real gases can be determined accurately by utilizing *generalized enthalpy* or *entropy departure charts* to account for the deviation from the ideal-gas behavior by using the following relations:

$$\bar{h}_2 - \bar{h}_1 = (\bar{h}_2 - \bar{h}_1)_{\text{ideal}} - R_u T_{\text{cr}}(Z_{h_2} - Z_{h_1})$$

$$\bar{u}_2 - \bar{u}_1 = (\bar{h}_2 - \bar{h}_1) - R_u(Z_2 T_2 - Z_1 T_1)$$

$$\bar{s}_2 - \bar{s}_1 = (\bar{s}_2 - \bar{s}_1)_{\text{ideal}} - R_u(Z_{s_2} - Z_{s_1})$$

where the values of Z_h and Z_s are determined from the generalized charts.

REFERENCES AND SUGGESTED READINGS

1. G. J. Van Wylen and R. E. Sonntag. *Fundamentals of Classical Thermodynamics*. 3rd ed. New York: John Wiley & Sons, 1985.

2. K. Wark and D. E. Richards. *Thermodynamics*. 6th ed. New York: McGraw-Hill, 1999.

PROBLEMS*

Partial Derivatives and Associated Relations

12–1C   Consider the function $z(x, y)$. Plot a differential surface on x-y-z coordinates and indicate ∂x, dx, ∂y, dy, $(\partial z)_x$, $(\partial z)_y$, and dz.

12–2C   What is the difference between partial differentials and ordinary differentials?

*Problems designated by a "C" are concept questions, and students are encouraged to answer them all. Problems designated by an "E" are in English units, and the SI users can ignore them. Problems with a CD-EES icon ⊛ are solved using EES, and complete solutions together with parametric studies are included on the enclosed DVD. Problems with a computer-EES icon 🖳 are comprehensive in nature, and are intended to be solved with a computer, preferably using the EES software that accompanies this text.

12–3C Consider the function $z(x, y)$, its partial derivatives $(\partial z/\partial x)_y$ and $(\partial z/\partial y)_x$, and the total derivative dz/dx.
(a) How do the magnitudes $(\partial x)_y$ and dx compare?
(b) How do the magnitudes $(\partial z)_y$ and dz compare?
(c) Is there any relation among dz, $(\partial z)_x$, and $(\partial z)_y$?

12–4C Consider a function $z(x, y)$ and its partial derivative $(\partial z/\partial y)_x$. Under what conditions is this partial derivative equal to the total derivative dz/dy?

12–5C Consider a function $z(x, y)$ and its partial derivative $(\partial z/\partial y)_x$. If this partial derivative is equal to zero for all values of x, what does it indicate?

12–6C Consider a function $z(x, y)$ and its partial derivative $(\partial z/\partial y)_x$. Can this partial derivative still be a function of x?

12–7C Consider a function $f(x)$ and its derivative df/dx. Can this derivative be determined by evaluating dx/df and taking its inverse?

12–8 Consider air at 400 K and 0.90 m³/kg. Using Eq. 12–3, determine the change in pressure corresponding to an increase of (a) 1 percent in temperature at constant specific volume, (b) 1 percent in specific volume at constant temperature, and (c) 1 percent in both the temperature and specific volume.

12–9 Repeat Problem 12–8 for helium.

12–10 Prove for an ideal gas that (a) the $P =$ constant lines on a T-v diagram are straight lines and (b) the high-pressure lines are steeper than the low-pressure lines.

12–11 Derive a relation for the slope of the $v =$ constant lines on a T-P diagram for a gas that obeys the van der Waals equation of state. *Answer: $(v - b)/R$*

12–12 Nitrogen gas at 400 K and 300 kPa behaves as an ideal gas. Estimate the c_p and c_v of the nitrogen at this state, using enthalpy and internal energy data from Table A–18, and compare them to the values listed in Table A–2b.

12–13E Nitrogen gas at 600 R and 30 psia behaves as an ideal gas. Estimate the c_p and c_v of the nitrogen at this state, using enthalpy and internal energy data from Table A–18E, and compare them to the values listed in Table A–2Eb.
Answers: 0.249 Btu/lbm · R, 0.178 Btu/lbm · R

12–14 Consider an ideal gas at 400 K and 100 kPa. As a result of some disturbance, the conditions of the gas change to 404 K and 96 kPa. Estimate the change in the specific volume of the gas using (a) Eq. 12–3 and (b) the ideal-gas relation at each state.

12–15 Using the equation of state $P(v - a) = RT$, verify (a) the cyclic relation and (b) the reciprocity relation at constant v.

The Maxwell Relations

12–16 Verify the validity of the last Maxwell relation (Eq. 12–19) for refrigerant-134a at 80°C and 1.2 MPa.

12–17 Reconsider Prob. 12–16. Using EES (or other) software, verify the validity of the last Maxwell relation for refrigerant-134a at the specified state.

12–18E Verify the validity of the last Maxwell relation (Eq. 12–19) for steam at 800°F and 400 psia.

12–19 Using the Maxwell relations, determine a relation for $(\partial s/\partial P)_T$ for a gas whose equation of state is $P(v - b) = RT$.
Answer: $-R/P$

12–20 Using the Maxwell relations, determine a relation for $(\partial s/\partial v)_T$ for a gas whose equation of state is $(P - a/v^2)(v - b) = RT$.

12–21 Using the Maxwell relations and the ideal-gas equation of state, determine a relation for $(\partial s/\partial v)_T$ for an ideal gas. *Answer: R/v*

The Clapeyron Equation

12–22C What is the value of the Clapeyron equation in thermodynamics?

12–23C Does the Clapeyron equation involve any approximations, or is it exact?

12–24C What approximations are involved in the Clapeyron-Clausius equation?

12–25 Using the Clapeyron equation, estimate the enthalpy of vaporization of refrigerant-134a at 40°C, and compare it to the tabulated value.

12–26 Reconsider Prob. 12–25. Using EES (or other) software, plot the enthalpy of vaporization of refrigerant-134a as a function of temperature over the temperature range −20 to 80°C by using the Clapeyron equation and the refrigerant-134a data in EES. Discuss your results.

12–27 Using the Clapeyron equation, estimate the enthalpy of vaporization of steam at 300 kPa, and compare it to the tabulated value.

12–28 Calculate the h_{fg} and s_{fg} of steam at 120°C from the Clapeyron equation, and compare them to the tabulated values.

12–29E Determine the h_{fg} of refrigerant-134a at 50°F on the basis of (a) the Clapeyron equation and (b) the Clapeyron-Clausius equation. Compare your results to the tabulated h_{fg} value.

12–30 Plot the enthalpy of vaporization of steam as a function of temperature over the temperature range 10 to 200°C by using the Clapeyron equation and steam data in EES.

12–31 Using the Clapeyron-Clausius equation and the triple-point data of water, estimate the sublimation pressure of water at −30°C and compare to the value in Table A–8.

General Relations for *du*, *dh*, *ds*, *c*$_v$, and *c*$_p$

12–32C Can the variation of specific heat c_p with pressure at a given temperature be determined from a knowledge of P-v-T data alone?

12–33 Show that the enthalpy of an ideal gas is a function of temperature only and that for an incompressible substance it also depends on pressure.

12–34 Derive expressions for (*a*) Δu, (*b*) Δh, and (*c*) Δs for a gas that obeys the van der Waals equation of state for an isothermal process.

12–35 Derive expressions for (*a*) Δu, (*b*) Δh, and (*c*) Δs for a gas whose equation of state is $P(v - a) = RT$ for an isothermal process. *Answers:* (*a*) 0, (*b*) $a(P_2 - P_1)$, (*c*) $-R \ln (P_2/P_1)$

12–36 Derive expressions for $(\partial u/\partial P)_T$ and $(\partial h/\partial v)_T$ in terms of P, v, and T only.

12–37 Derive an expression for the specific-heat difference $c_p - c_v$ for (*a*) an ideal gas, (*b*) a van der Waals gas, and (*c*) an incompressible substance.

12–38 Estimate the specific-heat difference $c_p - c_v$ for liquid water at 15 MPa and 80°C. *Answer:* 0.32 kJ/kg · K

12–39E Estimate the specific-heat difference $c_p - c_v$ for liquid water at 1000 psia and 150°F. *Answer:* 0.057 Btu/lbm · R

12–40 Derive a relation for the volume expansivity β and the isothermal compressibility α (*a*) for an ideal gas and (*b*) for a gas whose equation of state is $P(v - a) = RT$.

12–41 Estimate the volume expansivity β and the isothermal compressibility α of refrigerant-134a at 200 kPa and 30°C.

The Joule-Thomson Coefficient

12–42C What does the Joule-Thomson coefficient represent?

12–43C Describe the inversion line and the maximum inversion temperature.

12–44C The pressure of a fluid always decreases during an adiabatic throttling process. Is this also the case for the temperature?

12–45C Does the Joule-Thomson coefficient of a substance change with temperature at a fixed pressure?

12–46C Will the temperature of helium change if it is throttled adiabatically from 300 K and 600 kPa to 150 kPa?

12–47 Consider a gas whose equation of state is $P(v - a) = RT$, where a is a positive constant. Is it possible to cool this gas by throttling?

12–48 Derive a relation for the Joule-Thomson coefficient and the inversion temperature for a gas whose equation of state is $(P + a/v^2)v = RT$.

12–49 Estimate the Joule-Thomson coefficient of steam at (*a*) 3 MPa and 300°C and (*b*) 6 MPa and 500°C.

12–50E Estimate the Joule-Thomson coefficient of nitrogen at (*a*) 200 psia and 500 R and (*b*) 2000 psia and 400 R. Use nitrogen properties from EES or other source.

12–51E Reconsider Prob. 12–50E. Using EES (or other) software, plot the Joule-Thomson coefficient for nitrogen over the pressure range 100 to 1500 psia at the enthalpy values 100, 175, and 225 Btu/lbm. Discuss the results.

12–52 Estimate the Joule-Thomson coefficient of refrigerant-134a at 0.7 MPa and 50°C.

12–53 Steam is throttled slightly from 1 MPa and 300°C. Will the temperature of the steam increase, decrease, or remain the same during this process?

The *dh*, *du*, and *ds* of Real Gases

12–54C What is the enthalpy departure?

12–55C On the generalized enthalpy departure chart, the normalized enthalpy departure values seem to approach zero as the reduced pressure P_R approaches zero. How do you explain this behavior?

12–56C Why is the generalized enthalpy departure chart prepared by using P_R and T_R as the parameters instead of P and T?

12–57 Determine the enthalpy of nitrogen, in kJ/kg, at 175 K and 8 MPa using (*a*) data from the ideal-gas nitrogen table and (*b*) the generalized enthalpy departure chart. Compare your results to the actual value of 125.5 kJ/kg. *Answers:* (*a*) 181.5 kJ/kg, (*b*) 121.6 kJ/kg

12–58E Determine the enthalpy of nitrogen, in Btu/lbm, at 400 R and 2000 psia using (*a*) data from the ideal-gas nitrogen table and (*b*) the generalized enthalpy chart. Compare your results to the actual value of 177.8 Btu/lbm.

12–59 What is the error involved in the (*a*) enthalpy and (*b*) internal energy of CO_2 at 350 K and 10 MPa if it is assumed to be an ideal gas? *Answers:* (*a*) 50%, (*b*) 49%

12–60 Determine the enthalpy change and the entropy change of nitrogen per unit mole as it undergoes a change of state from 225 K and 6 MPa to 320 K and 12 MPa, (*a*) by assuming ideal-gas behavior and (*b*) by accounting for the deviation from ideal-gas behavior through the use of generalized charts.

12–61 Determine the enthalpy change and the entropy change of CO_2 per unit mass as it undergoes a change of state from 250 K and 7 MPa to 280 K and 12 MPa, (*a*) by assuming ideal-gas behavior and (*b*) by accounting for the deviation from ideal-gas behavior.

12–62 Methane is compressed adiabatically by a steady-flow compressor from 2 MPa and −10°C to 10 MPa and 110°C at a rate of 0.55 kg/s. Using the generalized charts, determine the required power input to the compressor. *Answer:* 133 kW
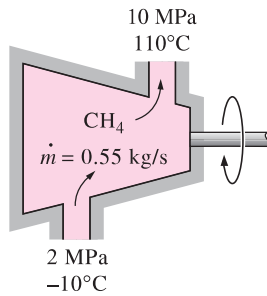
FIGURE P12–62

12–63 Propane is compressed isothermally by a piston–cylinder device from 100°C and 1 MPa to 4 MPa. Using the generalized charts, determine the work done and the heat transfer per unit mass of propane.

12–64 Reconsider Prob. 12–63. Using EES (or other) software, extend the problem to compare the solutions based on the ideal-gas assumption, generalized chart data, and real fluid data. Also extend the solution to methane.

12–65E Propane is compressed isothermally by a piston–cylinder device from 200°F and 200 psia to 800 psia. Using the generalized charts, determine the work done and the heat transfer per unit mass of the propane.
Answers: 45.3 Btu/lbm, 141 Btu/lbm

12–66 Determine the exergy destruction associated with the process described in Prob. 12–63. Assume $T_0 = 30°C$.

12–67 Carbon dioxide enters an adiabatic nozzle at 8 MPa and 450 K with a low velocity and leaves at 2 MPa and 350 K. Using the generalized enthalpy departure chart, determine the exit velocity of the carbon dioxide.   *Answer: 384 m/s*

12–68 Reconsider Prob. 12–67. Using EES (or other) software, compare the exit velocity to the nozzle assuming ideal-gas behavior, the generalized chart data, and EES data for carbon dioxide.

12–69 A 0.08-m^3 well-insulated rigid tank contains oxygen at 220 K and 10 MPa. A paddle wheel placed in the tank is turned on, and the temperature of the oxygen rises to 250 K. Using the generalized charts, determine (a) the final pressure in the tank and (b) the paddle-wheel work done during this process.   *Answers: (a) 12,190 kPa, (b) 393 kJ*

12–70 Carbon dioxide is contained in a constant-volume tank and is heated from 100°C and 1 MPa to 8 MPa. Determine the heat transfer and entropy change per unit mass of the carbon dioxide using (a) the ideal-gas assumption, (b) the generalized charts, and (c) real fluid data from EES or other sources.

Review Problems

12–71 For $\beta \geq 0$, prove that at every point of a single-phase region of an h-s diagram, the slope of a constant-pressure ($P = $ constant) line is greater than the slope of a constant-temperature ($T = $ constant) line, but less than the slope of a constant-volume ($v = $ constant) line.

12–72 Using the cyclic relation and the first Maxwell relation, derive the other three Maxwell relations.

12–73 Starting with the relation $dh = T\,ds + v\,dP$, show that the slope of a constant-pressure line on an h-s diagram (a) is constant in the saturation region and (b) increases with temperature in the superheated region.

12–74 Derive relations for (a) Δu, (b) Δh, and (c) Δs of a gas that obeys the equation of state $(P + a/v^2)v = RT$ for an isothermal process.

12–75 Show that

$$c_v = -T\left(\frac{\partial v}{\partial T}\right)_s\left(\frac{\partial P}{\partial T}\right)_v \quad \text{and} \quad c_p = T\left(\frac{\partial P}{\partial T}\right)_s\left(\frac{\partial v}{\partial T}\right)_P$$

12–76 Estimate the c_p of nitrogen at 300 kPa and 400 K, using (a) the relation in the above problem and (b) its definition. Compare your results to the value listed in Table A–2b.

12–77 Steam is throttled from 4.5 MPa and 300°C to 2.5 MPa. Estimate the temperature change of the steam during this process and the average Joule-Thomson coefficient.
Answers: −26.3°C, 13.1°C/MPa

12–78 A rigid tank contains 1.2 m^3 of argon at −100°C and 1 MPa. Heat is now transferred to argon until the temperature in the tank rises to 0°C. Using the generalized charts, determine (a) the mass of the argon in the tank, (b) the final pressure, and (c) the heat transfer.
Answers: (a) 35.1 kg, (b) 1531 kPa, (c) 1251 kJ

12–79 Argon gas enters a turbine at 7 MPa and 600 K with a velocity of 100 m/s and leaves at 1 MPa and 280 K with a velocity of 150 m/s at a rate of 5 kg/s. Heat is being lost to the surroundings at 25°C at a rate of 60 kW. Using the generalized charts, determine (a) the power output of the turbine and (b) the exergy destruction associated with the process.
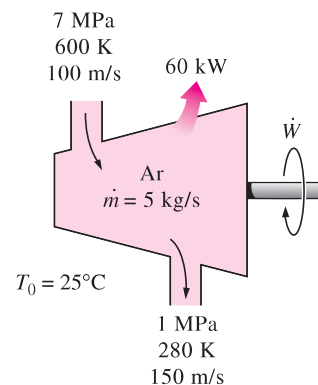

FIGURE P12–79

12–80 [EES] Reconsider Prob. 12–79. Using EES (or other) software, solve the problem assuming steam is the working fluid by using the generalized chart method and EES data for steam. Plot the power output and the exergy destruction rate for these two calculation methods against the turbine exit pressure as it varies over the range 0.1 to 1 MPa when the turbine exit temperature is 455 K.

12–81E Argon gas enters a turbine at 1000 psia and 1000 R with a velocity of 300 ft/s and leaves at 150 psia and 500 R with a velocity of 450 ft/s at a rate of 12 lbm/s. Heat is being lost to the surroundings at 75°F at a rate of 80 Btu/s. Using the generalized charts, determine (a) the power output of the turbine and (b) the exergy destruction associated with the process. *Answers:* (a) 922 hp, (b) 121.5 Btu/s

12–82 An adiabatic 0.2-m³ storage tank that is initially evacuated is connected to a supply line that carries nitrogen at 225 K and 10 MPa. A valve is opened, and nitrogen flows into the tank from the supply line. The valve is closed when the pressure in the tank reaches 10 MPa. Determine the final temperature in the tank (a) treating nitrogen as an ideal gas and (b) using generalized charts. Compare your results to the actual value of 293 K.
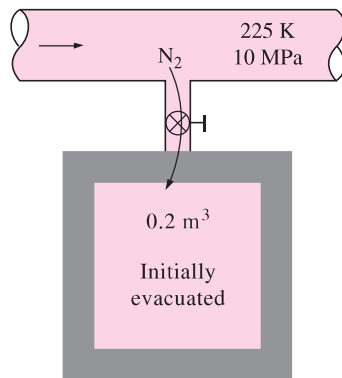

FIGURE P12–82

12–83 For a homogeneous (single-phase) simple pure substance, the pressure and temperature are independent properties, and any property can be expressed as a function of these two properties. Taking $v = v(P, T)$, show that the change in specific volume can be expressed in terms of the volume expansivity β and isothermal compressibility α as

$$\frac{dv}{v} = \beta \, dT - \alpha \, dP$$

Also, assuming constant average values for β and α, obtain a relation for the ratio of the specific volumes v_2/v_1 as a homogeneous system undergoes a process from state 1 to state 2.

12–84 Repeat Prob. 12–83 for an isobaric process.

12–85 The volume expansivity of water at 20°C is $\beta = 0.207 \times 10^{-6}$ K^{-1}. Treating this value as a constant, determine the change in volume of 1 m³ of water as it is heated from 10°C to 30°C at constant pressure.

12–86 The volume expansivity β values of copper at 300 K and 500 K are 49.2×10^{-6} K^{-1} and 54.2×10^{-6} K^{-1}, respectively, and β varies almost linearly in this temperature range. Determine the percent change in the volume of a copper block as it is heated from 300 K to 500 K at atmospheric pressure.

12–87 Starting with $\mu_{JT} = (1/c_p) [T(\partial v/\partial T)_p - v]$ and noting that $Pv = ZRT$, where $Z = Z(P, T)$ is the compressibility factor, show that the position of the Joule-Thomson coefficient inversion curve on the T-P plane is given by the equation $(\partial Z/\partial T)_P = 0$.

12–88 Consider an infinitesimal reversible adiabatic compression or expansion process. By taking $s = s(P, v)$ and using the Maxwell relations, show that for this process $Pv^k = $ constant, where k is the *isentropic expansion exponent* defined as

$$k = \frac{v}{P}\left(\frac{\partial P}{\partial v}\right)_s$$

Also, show that the isentropic expansion exponent k reduces to the specific heat ratio c_p/c_v for an ideal gas.

12–89 [EES] Refrigerant-134a undergoes an isothermal process at 60°C from 3 to 0.1 MPa in a closed system. Determine the work done by the refrigerant-134a by using the tabular (EES) data and the generalized charts, in kJ/kg.

12–90 Methane is contained in a piston–cylinder device and is heated at constant pressure of 4 MPa from 100 to 350°C. Determine the heat transfer, work and entropy change per unit mass of the methane using (a) the ideal-gas assumption, (b) the generalized charts, and (c) real fluid data from EES or other sources.

Fundamentals of Engineering (FE) Exam Problems

12–91 A substance whose Joule-Thomson coefficient is negative is throttled to a lower pressure. During this process, (select the correct statement)

(a) the temperature of the substance will increase.

(b) the temperature of the substance will decrease.

(c) the entropy of the substance will remain constant.

(d) the entropy of the substance will decrease.

(e) the enthalpy of the substance will decrease.

12–92 Consider the liquid–vapor saturation curve of a pure substance on the P-T diagram. The magnitude of the slope of the tangent line to this curve at a temperature T (in Kelvin) is

(a) proportional to the enthalpy of vaporization h_{fg} at that temperature.

(b) proportional to the temperature T.

(c) proportional to the square of the temperature T.

(d) proportional to the volume change v_{fg} at that temperature.

(e) inversely proportional to the entropy change s_{fg} at that temperature.

12–93 Based on the generalized charts, the error involved in the enthalpy of CO_2 at 350 K and 8 MPa if it is assumed to be an ideal gas is

(a) 0 (b) 20% (c) 35% (d) 26% (e) 65%

12–94 Based on data from the refrigerant-134a tables, the Joule-Thompson coefficient of refrigerant-134a at 0.8 MPa and 100°C is approximately

(a) 0 (b) −5°C/MPa (c) 11°C/MPa
(d) 8°C/MPa (e) 26°C/MPa

12–95 For a gas whose equation of state is $P(v − b) = RT$, the specified heat difference $c_p − c_v$ is equal to

(a) R (b) $R − b$ (c) $R + b$ (d) 0 (e) $R(1 + v/b)$

Design and Essay Problems

12–96 Consider the function $z = z(x, y)$. Write an essay on the physical interpretation of the ordinary derivative dz/dx and the partial derivative $(\partial z/\partial x)_y$. Explain how these two derivatives are related to each other and when they become equivalent.

12–97 There have been several attempts to represent the thermodynamic relations geometrically, the best known of these
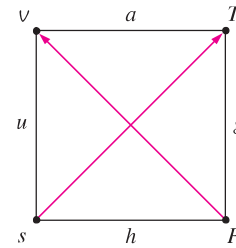

FIGURE P12–97

being Koenig's thermodynamic square shown in the figure. There is a systematic way of obtaining the four Maxwell relations as well as the four relations for du, dh, dg, and da from this figure. By comparing these relations to Koenig's diagram, come up with the rules to obtain these eight thermodynamic relations from this diagram.

12–98 Several attempts have been made to express the partial derivatives of the most common thermodynamic properties in a compact and systematic manner in terms of measurable properties. The work of P. W. Bridgman is perhaps the most fruitful of all, and it resulted in the well-known Bridgman's table. The 28 entries in that table are sufficient to express the partial derivatives of the eight common properties P, T, v, s, u, h, f, and g in terms of the six properties P, v, T, c_p, β, and α, which can be measured directly or indirectly with relative ease. Obtain a copy of Bridgman's table and explain, with examples, how it is used.