piston, which has a mass of 100 lb and face area of 1 ft². As electric current passes through the resistor, the volume of the air increases while the piston moves smoothly in the cylinder. The local acceleration of gravity is $g = 32.0 \text{ ft/s}^2$. Determine the pressure of the air in the piston-cylinder assembly, in lbf/in² and psig.

1.42 Warm air is contained in a piston-cylinder assembly oriented horizontally as shown in Fig. P1.42. The air cools slowly from an initial volume of 0.003 m³ to a final volume of 0.002 m³. During the process, the spring exerts a force that varies linearly from an initial value of 900 N to a final value of zero. The atmospheric pressure is 100 kPa, and the area of the piston face is 0.018 m². Friction between the piston and the cylinder wall can be neglected. For the air in the piston-cylinder assembly, determine the initial and final pressures, each in kPa and atm.

1.43 Air contained within a vertical piston-cylinder assembly is shown in Fig. P1.43. On its top, the 10-kg piston is attached to a spring and exposed to an atmospheric pressure of 1 bar. Initially, the bottom of the piston is at $x = 0$, and the spring exerts a negligible force on the piston. The valve is opened and air enters the cylinder from the supply line, causing the volume of the air within the cylinder to increase by $3.9 \times 10^{-4} \text{ m}^3$. The force exerted by the spring as the air expands within the cylinder varies linearly with $x$ according to

$$F_{\text{spring}} = kx$$

where $k = 10,000 \text{ N/m}$. The piston face area is $7.8 \times 10^{-3} \text{ m}^2$. Ignoring friction between the piston and the cylinder wall, determine the pressure of the air within the cylinder, in bar, when the piston is in its initial position. Repeat when the piston is in its final position. The local acceleration of gravity is $9.81 \text{ m/s}^2$.

1.44 Determine the total force, in kN, on the bottom of a $100 \times 50 \text{ m}$ swimming pool. The depth of the pool varies linearly along its length from 1 m to 4 m. Also, determine the pressure on the floor at the center of the pool, in kPa. The atmospheric pressure is 0.98 bar, the density of the water is 998.2 kg/m³, and the local acceleration of gravity is 9.8 m/s².

1.45 The pressure from water mains located at street level may be insufficient for delivering water to the upper floors of tall buildings. In such a case, water may be pumped up to a tank that feeds water to the building by gravity. For an open storage tank atop a 300-ft-tall building, determine the pressure, in lbf/in², at the bottom of the tank when filled to a depth of 20 ft. The density of water is 62.2 lb/ft³, $g = 32.0 \text{ ft/s}^2$, and the local atmospheric pressure is 14.7 lbf/in².

1.46 As shown in Figure P1.46, an inclined manometer is used to measure the pressure of the gas within the reservoir. (a) Using data on the figure, determine the gas pressure, in lbf/in². (b) Express the pressure as a gage or a vacuum pressure, as appropriate, in lbf/in². (c) What advantage does an inclined manometer have over the U-tube manometer shown in Figure 1.7?

1.47 The variation of pressure within the biosphere affects not only living things but also systems such as aircraft and underwater exploration vehicles.

(a) Plot the variation of atmospheric pressure, in atm, versus elevation $z$ above sea level, in km, ranging from 0 to 10 km. Assume that the specific volume of the atmosphere, in m³/kg, varies with the local pressure $p$, in kPa, according to $v = 72.435/p$.

(b) Plot the variation of pressure, in atm, versus depth $z$ below sea level, in km, ranging from 0 to 2 km. Assume
2.75 A gas within a piston–cylinder assembly undergoes a thermodynamic cycle consisting of three processes:

**Process 1–2:** Compression with \( pV = \text{constant} \), from \( p_1 = 1 \text{ bar} \), \( V_1 = 1.6 \text{ m}^3 \) to \( V_2 = 0.2 \text{ m}^3 \), \( U_2 - U_1 = 0 \).

**Process 2–3:** Constant pressure to \( V_3 = V_1 \).

**Process 3–1:** Constant volume, \( U_1 - U_3 = -3549 \text{ kJ} \).

There are no significant changes in kinetic or potential energy. Determine the heat transfer and work for Process 2–3, in kJ. Is this a power cycle or a refrigeration cycle?

2.76 A gas within a piston–cylinder assembly undergoes a thermodynamic cycle consisting of three processes:

**Process 1–2:** Constant volume, \( V = 0.028 \text{ m}^3 \), \( U_2 - U_1 = 26.4 \text{ kJ} \).

**Process 2–3:** Expansion with \( pV = \text{constant} \), \( U_3 = U_2 \).

**Process 3–1:** Constant pressure, \( p = 1.4 \text{ bar} \), \( W_{31} = -10.5 \text{ kJ} \).

There are no significant changes in kinetic or potential energy.

(a) Sketch the cycle on a \( p-V \) diagram.

(b) Calculate the net work for the cycle, in kJ.

(c) Calculate the heat transfer for process 2–3, in kJ.

(d) Calculate the heat transfer for process 3–1, in kJ.

Is this a power cycle or a refrigeration cycle?

2.77 As shown in Fig. P2.77, a gas within a piston–cylinder assembly undergoes a thermodynamic cycle consisting of three processes in series:

**Process 1–2:** Compression with \( U_2 = U_1 \).

**Process 2–3:** Constant-volume cooling to \( p_3 = 140 \text{ kPa} \), \( V_3 = 0.028 \text{ m}^3 \).

**Process 3–1:** Constant-pressure expansion with \( W_{31} = 10.5 \text{ kJ} \).

For the cycle, \( W_{\text{cycle}} = -8.3 \text{ kJ} \). There are no changes in kinetic or potential energy. Determine (a) the volume at state 1, in m³, (b) the work and heat transfer for process 1–2, each in kJ. (c) Can this be a power cycle? A refrigeration cycle? Explain.

![Fig. P2.77](image)

2.78 For a power cycle operating as in Fig. 2.17a, the heat transfers are \( Q_{\text{in}} = 50 \text{ kJ} \) and \( Q_{\text{out}} = 35 \text{ kJ} \). Determine the net work, in kJ, and the thermal efficiency.

2.79 The thermal efficiency of a power cycle operating as shown in Fig. 2.17a is 35%, and \( Q_{\text{out}} = 40 \text{ MJ} \). Determine the net work developed and the heat transfer \( Q_{\text{in}} \), each in MJ.

2.80 For a power cycle operating as in Fig. 2.17a, \( Q_{\text{in}} = 2600 \text{ Btu} \) and \( Q_{\text{out}} = 1800 \text{ Btu} \). What is the net work developed, in Btu, and the thermal efficiency?

2.81 For a power cycle operating as in Fig. 2.17a, \( W_{\text{cycle}} = 800 \text{ Btu} \) and \( Q_{\text{out}} = 1800 \text{ Btu} \). What is the thermal efficiency?

2.82 A power cycle receives energy by heat transfer from the combustion of fuel and develops power at a net rate of 150 MW. The thermal efficiency of the cycle is 40%.

(a) Determine the net rate at which the cycle receives energy by heat transfer, in MW.

(b) For 8000 hours of operation annually, determine the net work output, in kW · h per year.

(c) Evaluating the net work output at $0.08 per kW · h, determine the value of net work, in $ per year.

2.83 A power cycle has a thermal efficiency of 40% and generates electricity at a rate of 100 MW. The electricity is valued at $0.08 per kW · h. Based on the cost of fuel, the cost to supply \( Q_{\text{in}} \) is $4.50 per GJ. For 8000 hours of operation annually, determine, in $,

(a) the value of electricity generated per year.

(b) the annual fuel cost.

(c) Does the difference between the results of parts (a) and (b) represent profit? Discuss.

2.84 Shown in Fig. P2.84 is a cogeneration power plant operating in a thermodynamic cycle at steady state. The plant provides electricity to a community at a rate of 80 MW. The energy discharged from the power plant by heat transfer is denoted on the figure by \( Q_{\text{out}} \). Of this, 70 MW is provided to the community for water heating and the remainder is discarded to the environment without use. The electricity is valued at $0.08 per kW · h. If the cycle thermal efficiency is 40%, determine the (a) rate energy is added by heat transfer, \( Q_{\text{in}} \), in MW, (b) rate energy is discarded to the environment, in MW, and (c) value of the electricity generated, in $ per year.

![Fig. P2.84](image)

2.85 For each of the following, what plays the roles of the hot body and the cold body of the appropriate Fig. 2.17 schematic?

(a) Window air conditioner

(b) Nuclear submarine power plant

(c) Ground-source heat pump

2.86 In what ways do automobile engines operate analogously to the power cycle shown in Fig. 2.17a? How are they different? Discuss.

2.87 A refrigeration cycle operating as shown in Fig. 2.17b has heat transfer \( Q_{\text{out}} = 2400 \text{ Btu} \) and net work of \( W_{\text{cycle}} = 800 \text{ Btu} \). Determine the coefficient of performance for the cycle.

2.88 A refrigeration cycle operates as shown in Fig. 2.17b with a coefficient of performance \( \beta = 1.5 \). For the cycle, \( Q_{\text{out}} = 500 \text{ kJ} \). Determine \( Q_{\text{in}} \) and \( W_{\text{cycle}} \), each in kJ.
3.8 The following table lists temperatures and specific volumes of ammonia vapor at two pressures:

<table>
<thead>
<tr>
<th>P (lbf/in.²)</th>
<th>τ (ft²/lb)</th>
</tr>
</thead>
<tbody>
<tr>
<td>100</td>
<td>6.836</td>
</tr>
<tr>
<td>120</td>
<td>7.110</td>
</tr>
<tr>
<td>140</td>
<td>7.380</td>
</tr>
</tbody>
</table>

Data encountered in solving problems often do not fall exactly on the grid of values provided by property tables, and linear interpolation between adjacent table entries becomes necessary. Using the data provided here, estimate

(a) the specific volume at T = 120°F, p = 54 lbf/ft.², in ft³/lb.
(b) the temperature at p = 60 lbf/ft.², τ = 5.982 ft²/lb, in °F.
(c) the specific volume at T = 110°F, p = 58 lbf/ft.², in ft³/lb.

3.9 For H₂O, plot the following on a p-τ diagram drawn to scale on log-log coordinates:

(a) the saturated liquid and saturated vapor lines from the triple point to the critical point, with pressure in MPa and specific volume in m³/kg.
(b) lines of constant temperature at 100 and 300°C.

3.10 For H₂O, determine the specified property at the indicated state. Locate the state on a sketch of the T-τ diagram.

(a) p = 300 kPa, τ = 0.5 m³/kg, Find T, in °C.
(b) p = 28 MPa, T = 200°C, Find τ, in m³/kg.
(c) p = 1 MPa, T = 405°C, Find τ, in m³/kg.
(d) T = 100°C, x = 60%. Find τ, in m³/kg.

3.11 For each case, determine the specific volume at the indicated state. Locate the state on a sketch of the T-τ diagram.

(a) Water at p = 14.7 lbf/in.², T = 100°F. Find τ, in ft³/lb.
(b) Ammonia at T = −30°C, x = 50%. Find τ, in m³/kg.
(c) Refrigerant 134a at p = 1.5 MPa, T = 100°C. Find τ, in m³/kg.

3.12 For each case, determine the specified property at the indicated state. Locate the state on a sketch of the T-τ diagram.

(a) Water at 1 = 0.5 m³/kg, p = 3 bar, determine T, in °C.
(b) Ammonia at p = 11 lbf/in.², T = −20°F, determine τ, in ft³/lb.
(c) Propane at p = 1 MPa, T = 85°C, determine τ, in m³/kg.

3.13 Determine the mass, in kg, of 0.1 m³ of Refrigerant 134a at 4 bar, 100°C.

3.14 Determine the volume, in ft³, occupied by 2 lb of H₂O at a pressure of 1000 lbf/in.² and

(a) a temperature of 600°F.
(b) a quality of 80%.
(c) a temperature of 200°F.

3.15 A closed vessel with a volume of 2 ft³ contains 5 lb of Refrigerant 134a. A pressure sensor in the tank wall reads 71.39 lbf/in.² (gage). If the atmospheric pressure is 14.4 lbf/in.² what is the temperature of the refrigerant, in °F?

3.16 Two kg of a two-phase, liquid–vapor mixture of carbon dioxide (CO₂) exists at −40°C in a 0.05 m³ tank. Determine the quality of the mixture, if the values of specific volume for saturated liquid and saturated vapor CO₂ at −40°C are τₗ = 0.896 × 10⁻³ m³/kg and τᵥ = 3.824 × 10⁻³ m³/kg, respectively.

3.17 Determine the quality of a two-phase liquid–vapor mixture of

(a) H₂O at 20°C with a specific volume of 20 m³/kg.
(b) Propane at 15 bar with a specific volume of 0.02397 m³/kg.
(c) Refrigerant 134a at 60°C with a specific volume of 0.001 m³/kg.
(d) Ammonia at 1 MPa with a specific volume of 0.1 m³/kg.

3.18 Determine the quality of a two-phase liquid–vapor mixture of

(a) H₂O at 14.696 lbf/in.² with a specific volume of 25 ft³/lb.
(b) Propane at −80°F with a specific volume of 0.02653 ft³/lb.
(c) Refrigerant 134a at 50 lbf/in.² with a specific volume of 0.5 ft³/lb.
(d) Ammonia at −40°F with a specific volume of 20 ft³/lb.

3.19 A two-phase liquid–vapor mixture of ammonia at 100°F has a specific volume of 1.0 ft³/lb. Determine the quality of a two-phase liquid–vapor mixture at 0°F with the same specific volume.

3.20 A two-phase liquid–vapor mixture of a substance has a pressure of 150 bar and occupies a volume of 0.2 m³. The masses of saturated liquid and vapor present are 3.8 kg and 4.2 kg, respectively. Determine the specific volume of the mixture, in m³/kg.

3.21 As shown in Fig. P3.21, a closed, rigid cylinder contains different volumes of saturated liquid water and saturated water vapor at a temperature of 150°C. Determine the quality of the mixture, expressed as a percent.

3.22 A closed system consists of a two-phase liquid–vapor mixture of H₂O in equilibrium at 300°F. The quality of the mixture is 0.8 (80%) and the mass of saturated vapor present is 2 lb. Determine the mass of saturated liquid present, in lb, and the total volume of the system, in ft³.

3.23 Ammonia, initially saturated vapor at −4°C, undergoes a constant-specific volume process to 200 kPa. At the final state, determine the temperature, in °C, and the quality. Locate each state on a sketch of the T-τ diagram.

3.24 Water is contained in a closed, rigid, 0.2 m³ tank at an initial pressure of 5 bar and a quality of 50%. Heat transfer
volume until the pressure is 150 kPa. Friction between the piston and the cylinder wall and kinetic and potential energy effects are negligible. For the overall process of the water, determine the work and heat transfer, each in kJ.

3.71 A piston-cylinder assembly contains 2 lb of water, initially at 300°F. The water undergoes two processes in series: constant-volume heating followed by a constant-pressure process. At the end of the constant-volume process, the pressure is 100 lbf/in.² and the water is a two-phase, liquid–vapor mixture with a quality of 80%. At the end of the constant-pressure process, the temperature is 400°F. Neglect kinetic and potential energy effects.

(a) Sketch $T$–$v$ and $p$–$v$ diagrams showing the key states and the processes.
(b) Determine the work and heat transfer for each of the two processes, all in Btu.

3.72 A system consisting of 2 lb of water vapor, initially at 300°F and occupying a volume of 20 ft³, is compressed isothermally to a volume of 9.05 ft³. The system is then heated at constant volume to a final pressure of 120 lbf/in.². During the isothermal compression there is energy transfer by work of magnitude 90.8 Btu into the system. Kinetic and potential energy effects are negligible. Determine the heat transfer, in Btu, for each process.

3.73 Ammonia in a piston-cylinder assembly undergoes two processes in series. At the initial state, $p_1 = 120$ lbf/in.² and the quality is 100%. Process 1–2 occurs at constant volume until the temperature is 100°F. The second process, from state 2 to state 3, occurs at constant temperature, with $Q_{23} = -98.9$ Btu, until the quality is again 100%. Kinetic and potential energy effects are negligible. For 2.2 lb of ammonia, determine (a) the heat transfer for Process 1–2 and (b) the work for Process 2–3, each in Btu.

3.74 Three lb of water is contained in a piston-cylinder assembly, initially occupying a volume $V_i = 30$ ft³ at $T_i = 300°F$. The water undergoes two processes in series:

**Process 1-2:** Constant-temperature compression to $V_f = 11.19$ ft³, during which there is an energy transfer by heat from the water of 1273 Btu.

**Process 2-3:** Constant-volume heating to $p_f = 120$ lbf/in.². Sketch the two processes in series on a $T$–$v$ diagram. Neglecting kinetic and potential energy effects, determine the work in Process 1-2 and the heat transfer in Process 2-3, each in Btu.

3.75 As shown in Fig. P3.75, a piston-cylinder assembly fitted with stops contains 0.1 kg of water, initially at 1 MPa, 500°C. The water undergoes two processes in series:

**Process 1-2:** Constant-pressure cooling until the piston face rests against the stops. The volume occupied by the water is then one-half its initial volume.

**Process 2-3:** With the piston face resting against the stops, the water cools to 25°C. Sketch the two processes in series on a $p$–$v$ diagram. Neglecting kinetic and potential energy effects, evaluate for each process the work and heat transfer, each in kJ.

3.76 A system consisting of 2 kg of ammonia undergoes a cycle composed of the following processes:

**Process 1-2:** Constant volume from $p_1 = 10$ bar, $x_1 = 0.6$ to saturated vapor.

**Process 2-3:** Constant temperature to $p_3 = p_1$, $Q_{23} = +228$ kJ.

**Process 3-1:** Constant pressure. Sketch the cycle on $p$–$v$ and $T$–$v$ diagrams. Neglecting kinetic and potential energy effects, determine the net work for the cycle and the heat transfer for each process, all in kJ.

3.77 A system consisting of 1 kg of H₂O undergoes a power cycle composed of the following processes:

**Process 1-2:** Constant-pressure heating at 10 bar from saturated vapor.

**Process 2-3:** Constant-volume cooling to $p_3 = 5$ bar, $T_3 = 100°C$.

**Process 3-4:** Isothermal compression with $Q_{34} = -815.8$ kJ.

**Process 4-1:** Constant-volume heating. Sketch the cycle on $T$–$v$ and $p$–$v$ diagrams. Neglecting kinetic and potential energy effects, determine the thermal efficiency.

3.78 A system consisting of 1 lb of Refrigerant 22 undergoes a cycle composed of the following processes:
where \( r \) is the radial distance from the pipe centerline and \( V_0 \) is the centerline velocity. For each velocity distribution
(a) plot \( V/V_0 \) versus \( r/R \).
(b) derive expressions for the mass flow rate and the average velocity of the flow, \( V_{\text{ave}} \), in terms of \( V_0 \), \( R \), and \( \rho \), as required.
(c) derive an expression for the specific kinetic energy carried through an area normal to the flow. What is the percent error if the specific kinetic energy is evaluated in terms of the average velocity as \( (V_{\text{ave}})^2/2 \)?

Which velocity distribution adheres most closely to the idealizations of one-dimensional flow? Discuss.

4.22 Figure P4.22 shows a cylindrical tank being drained through a duct whose cross-sectional area is \( 3 \times 10^{-4} \) m\(^2\). The velocity of the water at the exit varies according to \((2gz)^{1/2}\), where \( z \) is the water level, in m, and \( g \) is the acceleration of gravity, 9.81 m/s\(^2\). The tank initially contains 2500 kg of liquid water. Taking the density of the water as \( 10^3 \) kg/m\(^3\), determine the time, in minutes, when the tank contains 900 kg of water.

![Fig. P4.22](image)

Energy Analysis of Control Volumes at Steady State

4.23 Steam enters a horizontal pipe operating at steady state with a specific enthalpy of 3000 kJ/kg and a mass flow rate of 0.5 kg/s. At the exit, the specific enthalpy is 1700 kJ/kg. If there is no significant change in kinetic energy from inlet to exit, determine the rate of heat transfer between the pipe and its surroundings, in kW.

4.24 Refrigerant 134a enters a horizontal pipe operating at steady state at 40°C, 300 kPa and a velocity of 40 m/s. At the exit, the temperature is 50°C and the pressure is 240 kPa. The pipe diameter is 0.04 m. Determine \( a \) the mass flow rate of the refrigerant, in kg/s, \( b \) the velocity at the exit, in m/s, and \( c \) the rate of heat transfer between the pipe and its surroundings, in kW.

4.25 As shown in Fig. P4.25, air enters a pipe at 25°C, 100 kPa with a volumetric flow rate of 23 m\(^3\)/h. On the outer pipe surface is an electrical resistor covered with insulation. With a voltage of 120 V, the resistor draws a current of 4 amps. Assuming the ideal gas model with \( c_p = 1.005 \) kJ/kg K for air and ignoring kinetic and potential energy effects, determine \( a \) the mass flow rate of the air, in kg/h, and \( b \) the temperature of the air at exit, in °C.

![Fig. P4.25](image)

4.26 Carbon dioxide gas is heated as it flows steadily through a 2.5-cm-diameter pipe. At the inlet, the pressure is 2 bar, the temperature is 300 K, and the velocity is 100 m/s. Determine the rate of heat transfer to the carbon dioxide, in kW.

4.27 Air at 600 kPa, 300 K enters a well-insulated, horizontal pipe having a diameter of 1.2 cm and exits at 120 kPa, 300 K. Apply the ideal gas model for air, determine at steady state \( a \) the inlet and exit velocities, each in m/s, and \( b \) the mass flow rate, in kg/s.

4.28 At steady state, air at 200 kPa, 52°C and a mass flow rate of 0.5 kg/s enters an insulated duct having differing inlet and exit cross-sectional areas. At the duct exit, the pressure of the air is 100 kPa, the velocity is 255 m/s, and the cross-sectional area is \( 2 \times 10^{-3} \) m\(^2\). Assuming the ideal gas model, determine
(a) the temperature of the air at the exit, in °C.
(b) the velocity of the air at the inlet, in m/s.
(c) the inlet cross-sectional area, in m\(^2\).

4.29 Refrigerant 134a flows at steady state through a horizontal pipe having an inside diameter of 4 cm, entering as saturated vapor at -8°C with a mass flow rate of 17 kg/min. Refrigerant vapor exits at a pressure of 2 bar. If the heat transfer rate to the refrigerant is 3.4 kW, determine the exit temperature, in °C, and the velocities at the inlet and exit, in m/s.

4.30 Steam enters a well-insulated, horizontal nozzle operating at steady state with a velocity of 10 m/s. If the specific enthalpy decreases by 45 kJ/kg, determine the exit temperature, in °C.

4.31 Steam enters a nozzle operating at steady state at 30 bar, 320°C, with a velocity of 100 m/s. The exit pressure and temperature are 10 bar and 200°C, respectively. The mass flow rate is 2 kg/s. Neglecting heat transfer and potential energy, determine
(a) the exit velocity, in m/s.
(b) the inlet and exit flow areas, in cm\(^2\).
4-33 Air enters an uninsulated nozzle operating at steady state at 760°F with negligible velocity and exits the nozzle at 520°F with a velocity of 1500 ft/s. Assuming ideal gas behavior and neglecting potential energy effects, determine the heat transfer per unit mass of air flowing, in Btu/lb.

4-34 Air with a mass flow rate of 5 lb/s enters a horizontal nozzle operating at steady state at 800°F, 50 lb/in.² and a velocity of 10 ft/s. At the exit, the temperature is 460°F and the velocity is 1510 ft/s. Using the ideal gas model for air, determine (a) the area at the inlet, in ft², and (b) the heat transfer between the nozzle and its surroundings, in Btu per lb of air flowing.

4-35 Helium gas flows through a well-insulated nozzle at steady state. The temperature and velocity at the inlet are 600°F and 175 ft/s, respectively. At the exit, the temperature is 450°F and the pressure is 50 lb/in.². The mass flow rate is 1 lb/s. Using the ideal gas model, and neglecting potential energy effects, determine the exit area, in ft².

4-36 Methane (CH₄) gas enters a horizontal, well-insulated nozzle operating at steady state at 80°C and a velocity of 10 m/s. Assuming ideal gas behavior for the methane, plot the temperature of the gas exiting the nozzle, in °C, versus the exit velocity ranging from 500 to 600 m/s.

4-37 As shown in Fig. P4.37, air enters the diffuser of a jet engine operating at steady state at 18 kPa, 216 K and a velocity of 265 m/s, all data corresponding to high-altitude flight. The air flows adiabatically through the diffuser and achieves a temperature of 250 K at the diffuser exit. Using the ideal gas model for air, determine the velocity of the air at the diffuser exit, in m/s.

4-39 Refrigerant 134a enters an insulated diffuser as a saturated vapor at 100 lb/in.² with a velocity of 1200 ft/s. At the exit, the pressure is 300 lb/in.² and the velocity is negligible. The diffuser operates at steady state and potential energy effects can be neglected. Determine the exit temperature, in °F.

4-40 Carbon dioxide gas enters a well-insulated diffuser at 20 lb/in.², 500°F, with a velocity of 800 ft/s through a flow area of 1.4 in.². At the exit, the flow area is 30 times the inlet area, and the velocity is 20 ft/s. The potential energy change from inlet to exit is negligible. For steady-state operation, determine the exit temperature, in °R, the exit pressure, in lb/in.² and the mass flow rate, in lb/s.

4-41 Steam enters a well-insulated turbine operating at steady state at 4 MPa with a specific enthalpy of 3015.4 kJ/kg and a velocity of 10 m/s. The steam expands to the turbine exit where the pressure is 0.07 MPa, specific enthalpy is 2431.7 kJ/kg, and the velocity is 90 m/s. The mass flow rate is 11.95 kg/s. Neglecting potential energy effects, determine the power developed by the turbine, in kW.

4-42 Hot combustion gases, modeled as air behaving as an ideal gas, enter a turbine at 145 lb/in.², 2700°F with a mass flow rate of 0.22 lb/s and exit at 29 lb/in.² and 1620°F. If heat transfer from the turbine to its surroundings occurs at a rate of 14 Btu/s, determine the power output of the turbine, in hp.

4-43 Air expands through a turbine from 10 bar, 900 K, to 1 bar, 500 K. The inlet velocity is small compared to the exit velocity of 100 m/s. The turbine operates at steady state and develops a power output of 3200 kW. Heat transfer between the turbine and its surroundings and potential energy effects are negligible. Calculate the mass flow rate of air, in kg/s, and the exit area, in m².

4-44 Air expands through a turbine operating at steady state on an instrumented test stand. At the inlet, \( p_1 = 160 \text{ lb/in.}^2, \quad T_1 = 1350\degree \text{F} \), and at the exit, \( p_2 = 14.8 \text{ lb/in.}^2 \). The mass flow rate of air entering the turbine is 10.5 lb/s, and the power developed is measured as 2550 horsepower. Neglecting heat transfer and kinetic and potential energy effects, determine the exit temperature, \( T_2 \), in °R.

4-45 Steam enters a turbine operating at steady state at 800°F and 500 lb/in.² and leaves at 0.8 lb/in.² with a quality of 93%. The turbine develops 15,000 hp, and heat transfer from the turbine to the surroundings occurs at a rate of \( 2.5 \times 10^5 \text{ Btu/h} \). Neglecting kinetic and potential energy changes from inlet to exit, determine the volumetric flow rate of the steam at the inlet, in ft³/h.

4-46 A well-insulated turbine operating at steady state develops 23 MW of power for a steam flow rate of 40 kg/s. The steam enters at 360°C with a velocity of 35 m/s and exits as saturated vapor at 0.06 bar with a velocity of 120 m/s. Neglecting potential energy effects, determine the inlet pressure, in bar.

4-47 Steam enters a turbine operating at steady state with a mass flow of 10 kg/min, a specific enthalpy of 3100 kJ/kg, and a velocity of 30 m/s. At the exit, the specific enthalpy is 2300 kJ/kg and the velocity is 45 m/s. The elevation of the inlet is 3 m higher than at the exit. Heat transfer from the turbine to its surroundings occurs at a rate of 1.1 kJ per kg
of steam flowing. Let $g = 9.81 \text{ m/s}^2$. Determine the power developed by the turbine, in kW.

4.48 Steam enters a turbine operating at steady state at 2 MPa, 360°C with a velocity of 100 m/s. Saturated vapor exits at 0.1 MPa and a velocity of 50 m/s. The elevation of the inlet is 3 m higher than at the exit. The mass flow rate of the steam is 15 kg/s, and the power developed is 7 MW. Let $g = 9.81 \text{ m/s}^2$. Determine (a) the area at the inlet, in m$^2$, and (b) the rate of heat transfer between the turbine and its surroundings, in kW.

4.49 The intake to a hydraulic turbine installed in a flood control dam is located at an elevation of 10 m above the turbine exit. Water enters at 20°C with negligible velocity and exits from the turbine at 10 m/s. The water passes through the turbine with no significant changes in temperature or pressure between the inlet and exit, and heat transfer is negligible. The acceleration of gravity is constant at $g = 9.81 \text{ m/s}^2$. If the power output at steady state is 500 kW, what is the mass flow rate of water, in kg/s?

4.50 Steam enters the first-stage turbine shown in Fig. P4.50 at 40 bar and 500°C with a volumetric flow rate of 90 m$^3$/min. Steam exits the turbine at 20 bar and 400°C. The steam is then reheated at constant pressure to 500°C before entering the second-stage turbine. Steam leaves the second stage as saturated vapor at 0.6 bar. For operation at steady state, and ignoring stray heat transfer and kinetic and potential energy effects, determine the

(a) mass flow rate of the steam, in kg/h.
(b) total power produced by the two stages of the turbine, in kW.
(c) rate of heat transfer to the steam flowing through the reheater, in kW.

4.51 Steam at 1600 lb/in.$^2$, 1000°F, and a velocity of 2 ft/s enters a turbine operating at steady state. As shown in Fig. P4.51, 22% of the entering mass flow is extracted at 160 lb/in.$^2$, 450°F, with a velocity of 10 ft/s. The rest of the steam exits as a two-phase liquid–vapor mixture at 1 lb/in.$^2$, with a quality of 85% and a velocity of 150 ft/s. The turbine develops a power output of $9 \times 10^6$ Btu/h. Neglecting potential energy effects and heat transfer between the turbine and its surroundings, determine

(a) the mass flow rate of the steam entering the turbine, in lb/h.
(b) the diameter of the extraction duct, in ft.

$$W_{\text{net}} = 9 \times 10^6 \text{ Btu/h}$$

4.52 Air enters a compressor operating at steady state at 1 atm with a specific enthalpy of 290 kJ/kg and exits at a higher pressure with a specific enthalpy of 1023 kJ/kg. The mass flow rate is 0.1 kg/s. If the compressor power input is 77 kW, determine the rate of heat transfer between the compressor and its surroundings, in kW. Neglect kinetic and potential energy effects and use the ideal gas model.

4.53 Air enters a compressor operating at steady state at 1.05 bar, 300 K, with a volumetric flow rate of 12 m$^3$/min and exits at 12 bar, 400 K. Heat transfer occurs at a rate of 2 kW from the compressor to its surroundings. Assuming the ideal gas model for air and neglecting kinetic and potential energy effects, determine the power input, in kW.

4.54 Nitrogen is compressed in an axial-flow compressor operating at steady state from a pressure of 15 lb/in.$^2$ and a temperature of 50°F to a pressure 60 lb/in.$^2$. The gas enters the compressor through a 6-in.-diameter duct with a velocity of 30 ft/s and exits at 198°F with a velocity of 80 ft/s. Using the ideal gas model, and neglecting stray heat transfer and potential energy effects, determine the compressor power input, in hp.

4.55 Refrigerant 134a enters a compressor operating at steady state as saturated vapor at 0.12 MPa and exits at 1.2 MPa and 70°C at a mass flow rate of 0.108 kg/s. As the refrigerant passes through the compressor, heat transfer to the surroundings occurs at a rate of 0.32 kW. Determine at steady state the power input to the compressor, in kW.
9. When a power plant discharges cooling water to a river at a temperature higher than that of the river, what are the possible effects on the aquatic life of the river?

10. Referring to Eqs. 5.10 and 5.11, how might the coefficients of performance of refrigeration cycles and heat pumps be increased?

11. Is it possible for the coefficient of performance of a refrigeration cycle to be less than one? To be greater than one? Answer the same questions for a heat pump cycle.

12. A hot combustion gas enters a turbine operating at steady state and expands adiabatically to a lower pressure. Would you expect the power output to be greater in an internally reversible expansion or an actual expansion?

13. Refrigerant 22 enters a compressor operating at steady state and is compressed adiabatically to a higher pressure. Would you expect the power input to the compressor to be greater in an internally reversible compression or an actual compression?

Problems: Developing engineering skills

Exploring the Second Law

5.1 Complete the demonstration of the equivalence of the Clausius and Kelvin–Planck statements of the second law given in Sec. 5.2 by showing that a violation of the Kelvin–Planck statement implies a violation of the Clausius statement.

5.2 An inventor claims to have developed a device that undergoes a thermodynamic cycle while communicating thermally with two reservoirs. The system receives energy $Q_c$ from the cold reservoir and discharges energy $Q_h$ to the hot reservoir while delivering a net amount of work to its surroundings. There are no other energy transfers between the device and its surroundings. Evaluate the inventor’s claim using (a) the Clausius statement of the second law, and (b) the Kelvin–Planck statement of the second law.

5.3 Classify the following processes of a closed system as possible, impossible, or indeterminate.

<table>
<thead>
<tr>
<th>Entropy Change</th>
<th>Entropy Transfer</th>
<th>Entropy Production</th>
</tr>
</thead>
<tbody>
<tr>
<td>(a) &gt;0</td>
<td>0</td>
<td>&gt;0</td>
</tr>
<tr>
<td>(b) &lt;0</td>
<td>0</td>
<td>&lt;0</td>
</tr>
<tr>
<td>(c) 0</td>
<td>&gt;0</td>
<td>0</td>
</tr>
<tr>
<td>(d) &gt;0</td>
<td>&gt;0</td>
<td>&gt;0</td>
</tr>
<tr>
<td>(e) 0</td>
<td>&lt;0</td>
<td>&lt;0</td>
</tr>
<tr>
<td>(f) &gt;0</td>
<td>&lt;0</td>
<td>0</td>
</tr>
<tr>
<td>(g) &lt;0</td>
<td>0</td>
<td>0</td>
</tr>
</tbody>
</table>

5.4 As shown in Fig. P5.4, a hot thermal reservoir is separated from a cold thermal reservoir by a cylindrical rod insulated on its lateral surface. Energy transfer by conduction between the two reservoirs takes place through the rod, which remains at steady state. Using the Kelvin–Planck statement of the second law, demonstrate that such a process is irreversible.

5.5 As shown in Fig. P5.5, a rigid insulated tank is divided into halves by a partition. On one side of the partition is a gas. The other side is initially evacuated. A valve in the partition is opened and the gas expands to fill the entire volume. Using the Kelvin–Planck statement of the second law, demonstrate that this process is irreversible.

5.6 Answer the following true or false.

(a) A process that violates the second law of thermodynamics violates the first law of thermodynamics.

(b) When a net amount of work is done on a closed system undergoing an internally reversible process, a net heat transfer of energy from the system also occurs.

(c) A closed system can experience an increase in entropy only when a net amount of entropy is transferred into the system.

(d) The change in entropy of a closed system is the same for every process between two specified end states.

5.7 Complete the discussion of the Kelvin–Planck statement of the second law in the box of Sec. 5.4 by showing that if a system undergoes a thermodynamic cycle reversibly while communicating thermally with a single reservoir, the equality in Eq. 5.3 applies.

5.8 A reversible power cycle $R$ and an irreversible power cycle $I$ operate between the same two reservoirs.

(a) If each cycle receives the same amount of energy $Q_h$ from the hot reservoir, show that cycle $I$ necessarily discharges more energy $Q_c$ to the cold reservoir than cycle $R$. Discuss the implications of this for actual power cycles.
(b) If each cycle develops the same net work, show that cycle I necessarily receives more energy $Q_H$ from the hot reservoir than cycle R. Discuss the implications of this for actual power cycles.

5.9 A power cycle I and a reversible power cycle R operate between the same two reservoirs, as shown in Fig. 5.6. Cycle I has a thermal efficiency equal to two-thirds of that for cycle R. Using the Kelvin–Planck statement of the second law, prove that cycle I must be irreversible.

5.10 Provide the details left to the reader in the demonstration of the second Carnot corollary given in the box of Sec. 5.6.2.

5.31 Using the Kelvin–Planck statement of the second law of thermodynamics, demonstrate the following corollaries:

(a) The coefficient of performance of an irreversible refrigeration cycle is always less than the coefficient of performance of a reversible refrigeration cycle when both exchange energy by heat transfer with the same two reservoirs.

(b) All reversible refrigeration cycles operating between the same two reservoirs have the same coefficient of performance.

(c) The coefficient of performance of an irreversible heat pump cycle is always less than the coefficient of performance of a reversible heat pump cycle when both exchange energy by heat transfer with the same two reservoirs.

(d) All reversible heat pump cycles operating between the same two reservoirs have the same coefficient of performance.

5.12 Before introducing the temperature scale now known as the Kelvin scale, Kelvin suggested a logarithmic scale in which the function $\psi$ of Sec. 5.8.1 takes the form

$$\psi = \exp \frac{\theta_C}{\exp \theta_H}$$

where $\theta_H$ and $\theta_C$ denote, respectively, the temperatures of the hot and cold reservoirs on this scale.

(a) Show that the relation between the Kelvin temperature $T$ and the temperature $\theta$ on the logarithmic scale is

$$\theta = \ln T + C$$

where $C$ is a constant.

(b) On the Kelvin scale, temperatures vary from 0 to $+\infty$. Determine the range of temperature values on the logarithmic scale.

(c) Obtain an expression for the thermal efficiency of any system undergoing a reversible power cycle while operating between reservoirs at temperatures $\theta_H$ and $\theta_C$ on the logarithmic scale.

5.13 Demonstrate that the gas temperature scale (Sec. 5.8.2) is identical to the Kelvin temperature scale (Sec. 5.8.1).

5.14 The platinum resistance thermometer is said to be the most important of the three thermometers specified in ITS-90 because it covers the broad, practically significant interval from 13.8 K to 1234.59 K. What is the operating principle of resistance thermometry and why is platinum specified for use in ITS-90?

5.35 The relation between resistance $R$ and temperature $T$ for a thermistor closely follows

$$R = R_0 \exp \left[ \beta \left( \frac{1}{T} - \frac{1}{T_0} \right) \right]$$

where $R_0$ is the resistance, in ohms ($\Omega$), measured at temperature $T_0$ (K) and $\beta$ is a material constant with units of K$^{-1}$. For a particular thermistor $R_0 = 2.2 \Omega$ at $T_0 = 310$ K. From a calibration test, it is found that $R = 0.31 \Omega$ at $T = 422$ K. Determine the value of $\beta$ for the thermistor and make a plot of resistance versus temperature.

5.36 Over a limited temperature range, the relation between electrical resistance $R$ and temperature $T$ for a resistance temperature detector is

$$R = R_0 [1 + \alpha (T - T_0)]$$

where $R_0$ is the resistance, in ohms ($\Omega$), measured at reference temperature $T_0$ (in °F) and $\alpha$ is a material constant with units of (°F)$^{-1}$. The following data are obtained for a particular resistance thermometer:

<p>| | |</p>
<table>
<thead>
<tr>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Test 1</td>
<td>32</td>
</tr>
<tr>
<td>Test 2</td>
<td>196</td>
</tr>
</tbody>
</table>

What temperature would correspond to a resistance of 51.47 Ω on this thermometer?

**Power Cycle Applications**

5.37 The data listed below are claimed for a power cycle operating between hot and cold reservoirs at 1000 K and 300 K, respectively. For each case, determine whether the cycle operates reversibly, operates irreversibly, or is impossible.

(a) $Q_H = 600$ kJ, $W_{cycle} = 300$ kJ, $Q_C = 300$ kJ
(b) $Q_H = 400$ kJ, $W_{cycle} = 280$ kJ, $Q_C = 120$ kJ
(c) $Q_H = 700$ kJ, $W_{cycle} = 300$ kJ, $Q_C = 500$ kJ
(d) $Q_H = 800$ kJ, $W_{cycle} = 600$ kJ, $Q_C = 200$ kJ

5.38 A power cycle receives energy $Q_H$ by heat transfer from a hot reservoir at $T_H = 1500$°R and rejects energy $Q_C$ by heat transfer to a cold reservoir at $T_C = 500$°R. For each of the following cases, determine whether the cycle operates reversibly, operates irreversibly, or is impossible.

(a) $Q_H = 900$ Btu, $W_{cycle} = 450$ Btu
(b) $Q_H = 900$ Btu, $Q_C = 300$ Btu
(c) $W_{cycle} = 600$ Btu, $Q_C = 400$ Btu
(d) $\eta = 70\%$

5.39 A power cycle operating at steady state receives energy by heat transfer at a rate $\dot{Q}_H$ at $T_H = 1000$ K and rejects energy by heat transfer to a cold reservoir at a rate $\dot{Q}_C$ at $T_C = 300$ K. For each of the following cases, determine whether the cycle operates reversibly, operates irreversibly, or is impossible.

(a) $\dot{Q}_H = 500$ kW, $\dot{Q}_C = 100$ kW
(b) $\dot{Q}_H = 500$ kW, $W_{cycle} = 250$ kW, $\dot{Q}_C = 200$ kW
(c) $W_{cycle} = 350$ kW, $Q_C = 150$ kW
(d) $\dot{Q}_H = 500$ kW, $Q_C = 200$ kW
compression occurs at 500°F and the heat added per cycle is 40.0 Btu. Assuming the ideal gas model for the air, determine
(a) the pressures at the end of the isothermal expansion, the adiabatic expansion, and the isothermal compression, each in lb/in².
(b) the net work developed per cycle, in Btu.
(c) the thermal efficiency.

6.31 Air in a piston-cylinder assembly undergoes a Carnot power cycle. The isothermal expansion and compression processes occur at 1400 K and 350 K, respectively. The pressures at the beginning and end of the isothermal compression are 100 kPa and 500 kPa, respectively. Assuming the ideal gas model with \( c_p = 1.005 \text{ kJ/kg} \cdot \text{K} \), determine
(a) the pressures at the beginning and end of the isothermal expansion, each in kPa.
(b) the heat transfer and work, in kJ/kg, for each process.
(c) the thermal efficiency.

6.32 Water in a piston-cylinder assembly undergoes a Carnot power cycle. At the beginning of the isothermal expansion, the temperature is 250°C and the quality is 80%. The isothermal expansion continues until the pressure is 2 MPa. The adiabatic expansion then occurs to a final temperature of 175°C.
(a) Sketch the cycle on T-s coordinates.
(b) Determine the heat transfer and work, in kJ/kg, for each process.
(c) Evaluate the thermal efficiency.

6.33 A Carnot power cycle operates at steady state as shown in Fig. 5.15 with water as the working fluid. The boiler pressure is 200 lb/in² with saturated liquid entering and saturated vapor exiting. The condenser pressure is 20 lb/in².
(a) Sketch the cycle on T-s coordinates.
(b) Determine the heat transfer and work for each process, in Btu per lb of water flowing.
(c) Evaluate the thermal efficiency.

6.34 Figure P6.34 shows a Carnot heat pump cycle operating at steady state with ammonia as the working fluid. The condenser temperature is 120°F, with saturated vapor entering and saturated liquid exiting. The evaporator temperature is 10°F.
(a) Determine the heat transfer and work for each process, in Btu per lb of ammonia flowing.
(b) Evaluate the coefficient of performance for the heat pump.
(c) Evaluate the coefficient of performance for a Carnot power cycle operating as shown in the figure.

6.35 Figure P6.35 gives the schematic of a vapor power plant in which water steadily circulates through the four components shown. The water flows through the boiler and condenser at constant pressure, and flows through the turbine and pump adiabatically.
(a) Sketch the cycle on T-s coordinates.
(b) Determine the thermal efficiency and compare with the thermal efficiency of a Carnot cycle operating between the same maximum and minimum temperatures.

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![Diagram](image-url)
6.87 Steam enters a well-insulated nozzle operating at steady state at 100°F, 500 lbf/in.² and a velocity of 10 ft/s. At the nozzle exit, the pressure is 14.7 lbf/in.² and the velocity is 4055 ft/s. Determine the rate of entropy production, in Btu/°R per lb of steam flowing.

6.88 Air at 400 kPa, 970 K enters a turbine operating at steady state and exits at 100 kPa, 670 K. Heat transfer from the turbine occurs at an average outer surface temperature of 315 K at the rate of 30 kJ per kg of air flowing. Kinetic and potential energy effects are negligible. For air as an ideal gas with $c_p = 1.1 \text{ kJ/kg} \cdot \text{K}$, determine (a) the rate power is developed, in kJ per kg of air flowing, and (b) the rate of entropy production within the turbine, in kJ/K per kg of air flowing.

6.89 Steam at 240°C, 700 kPa enters an open feedwater heater operating at steady state with a mass flow rate of 0.5 kg/s. A separate stream of liquid water enters at 45°C, 700 kPa with a mass flow rate of 4 kg/s. A single mixed stream exits at 700 kPa and temperature $T$. Stray heat transfer and kinetic and potential energy effects can be ignored. Determine (a) $T$, in °C, and (b) the rate of entropy production within the feedwater heater, in kW/K. (c) Locate the three principal states on a sketch of the $T$–s diagram.

6.90 By injecting liquid water into superheated vapor, the desuperheater shown in Fig. P6.90 has a saturated vapor stream at its exit. Steady-state operating data are shown on the figure. Ignoring stray heat transfer and kinetic and potential energy effects, determine (a) the mass flow rate of the superheated vapor stream, in kg/min, and (b) the rate of entropy production within the desuperheater, in kW/K.

6.91 Air at 600 kPa, 330 K enters a well-insulated, horizontal pipe having a diameter of 1.2 cm and exits at 120 kPa, 300 K. Applying the ideal gas model for air, determine at steady state (a) the inlet and exit velocities, each in m/s, (b) the mass flow rate, in kg/s, and (c) the rate of entropy production, in kW/K.

6.92 At steady state, air at 200 kPa, 52°C and a mass flow rate of 0.5 kg/s enters an insulated duct having differing inlet and exit cross-sectional areas. At the duct exit, the pressure of the air is 100 kPa, the velocity is 255 m/s, and the cross-sectional area is $2 \times 10^{-4}$ m². Assuming the ideal gas model, determine

(a) the temperature of the air at the exit, in °C.
(b) the velocity of the air at the inlet, in m/s.
(c) the inlet cross-sectional area, in m².
(d) the rate of entropy production within the duct, in kW/K.

6.93 For the computer of Example 4.8, determine the rate of entropy production, in W/K, when air exits at 32°C. Ignore the change in pressure between the inlet and exit.

6.94 For the computer of Problem 4.86, determine the rate of entropy production, in kW/K, ignoring the change in pressure between the inlet and exit.

6.95 For the water-jacketed electronics housing of Problem 4.87, determine the rate of entropy production, in kW/K, when water exits at 26°C.

6.96 Electronic components are mounted on the inner surface of a horizontal cylindrical duct whose inner diameter is 0.2 m, as shown in Fig. P6.96. To prevent overheating of the electronics, the cylinder is cooled by a stream of air flowing through it and by convection from its outer surface. Air enters the duct at 25°C, 1 bar and a velocity of 0.3 m/s and exits at 40°C with negligible changes in kinetic energy and
7.7 When matter flows across the boundary of a control volume, an energy transfer by work, called flow work, occurs. The rate is \( m(\dot{pu}) \) where \( m \), \( p \), and \( u \) denote the mass flow rate, pressure, and specific volume, respectively, of the matter crossing the boundary (see Sec. 4.4.2). Show that the exergy transfer accompanying flow work is given by \( m(\dot{pu} - \dot{pu}_0) \), where \( p_0 \) is the pressure at the dead state.

7.8 When matter flows across the boundary of a control volume, an exergy transfer accompanying mass flow occurs, which is given by \( m \dot{q} \theta \), where \( \theta \) is the specific exergy (Eq. 7.2) and \( m \) is the mass flow rate. An exergy transfer accompanying flow work, which is given by the result of Problem 7.7, also occurs at the boundary. Show that the sum of these exergy transfers is given by \( m \dot{q} \theta \), where \( \theta_0 \) is the specific flow exergy (Eq. 7.14).

7.9 For an ideal gas with constant specific heat ratio \( k \), show that in the absence of significant effects of motion and gravity the specific flow exergy can be expressed as

\[
\frac{\theta_0}{c_p T_0} = \frac{T}{T_0} - 1 - \ln \frac{T}{T_0} + \ln \left( \frac{p}{p_0} \right)^{\frac{k}{k-1}a}
\]

(a) For \( k = 1.2 \) develop plots of \( \frac{\theta_0}{c_p T_0} \) versus \( T/T_0 \) for \( p/p_0 = 0.25, 0.5, 1, 2, 4 \). Repeat for \( k = 1.3 \) and 1.4.

(b) The specific flow exergy can take on negative values when \( p/p_0 < 1 \). What does a negative specific value mean physically?

7.10 An ideal gas with constant specific heat ratio \( k \) enters a turbine operating at steady state at \( T_1 \) and \( p_1 \) and expands adiabatically to \( T_2 \) and \( p_2 \). When would the value of the exergetic turbine efficiency exceed the value of the isentropic turbine efficiency? Discuss. Ignore the effects of motion and gravity.

7.11 A system consists of 5 kg of water at 10°C and 1 bar. Determine the exergy, in kJ, if the system is at rest and zero elevation relative to an exergy reference environment for which \( T_0 = 20°C, p_0 = 1 \) bar.

7.12 Determine the exergy, in kJ, at 0.7 bar, 90°C for 1 kg of (a) water, (b) Refrigerant 134a, (c) air as an ideal gas with \( c_p \) constant. In each case, the mass is at rest and zero elevation relative to an exergy reference environment for which \( T_0 = 20°C, p_0 = 1 \) bar.

7.13 Determine the specific exergy, in kJ/kg, at 0.01°C of water as (a) saturated vapor, (b) saturated liquid, (c) saturated solid. In each case, consider a fixed mass at rest and zero elevation relative to an exergy reference environment for which \( T_0 = 20°C, p_0 = 1 \) bar.

7.14 Determine the specific exergy, in Btu, of one pound mass of (a) saturated water vapor at 212°F, (b) saturated liquid water at 40°F, (c) ammonia at -40°F, 6 lbm/in.². In each case, consider a fixed mass at rest and zero elevation relative to an exergy reference environment for which \( T_0 = 70°F, p_0 = 14.7 \) lbm/in.².

7.15 A balloon filled with helium at 20°C, 1 bar and a volume of 0.5 m³ is moving with a velocity of 15 m/s at an elevation of 0.5 km relative to an exergy reference environment for which \( T_0 = 20°C, p_0 = 1 \) bar. Using the ideal gas model, determine the specific exergy of the helium, in kJ.

7.16 A vessel contains carbon dioxide. Using the ideal gas model (a) determine the specific exergy of the gas, in Btu/lb, at \( p = 90 \) lbm/in.² and \( T = 200°F \), (b) plot the specific exergy of the gas, in Btu/lb, versus pressure ranging from 15 to 90 lbm/in.², for \( T = 80°F \), (c) plot the specific exergy of the gas, in Btu/lb, versus temperature ranging from 80 to 200°F, for \( p = 15 \) lbm/in.².

7.17 Oxygen \( (O_2) \) at temperature \( T \) and 1 atm fills a balloon at rest on the surface of the earth at a location where the ambient temperature is \( 40°F \) and the ambient pressure is 1 atm. Using the ideal gas model with \( c_p = 0.22 \) Btu/lb·°R, plot the specific exergy of the oxygen, in Btu/lb, relative to the earth and its atmosphere at this location versus \( T \) ranging from 500 to 600°F.

7.18 A vessel contains 1 lb of air at pressure \( p = 200°F \). Using the ideal gas model, plot the specific exergy of the air, in Btu/lb, for \( p \) ranging from 0.5 to 2 atm. The air is at rest and negligible elevation relative to an exergy reference environment for which \( T_0 = 60°F, p_0 = 1 \) atm.

7.19 Determine the specific exergy, in kJ/kg, at 0.6 bar, -10°C of (a) ammonia, (b) Refrigerant 22, (c) Refrigerant 134a. Let \( T_0 = 0°C, p_0 = 1 \) bar and ignore the effects of motion and gravity.

7.20 Consider a two-phase solid–vapor mixture of water at -10°C. Each phase present has the same mass. Determine the specific exergy, in kJ/kg, if \( T_0 = 20°C, p_0 = 1 \) atm, and there are no significant effects of motion or gravity.

7.21 Determine the exergy, in kJ, of the contents of a 2 m³ storage tank, if the tank is filled with (a) air as an ideal gas at 400°C and 0.55 bar, (b) water vapor at 400°C and 0.35 bar. Ignore the effects of motion and gravity and let \( T_0 = 17°C, p_0 = 1 \) atm.

7.22 Refrigerant 134a vapor initially at 1 bar and 20°C fills a rigid vessel. The vapor is cooled until the temperature becomes -32°C. There is no work during the process. For the refrigerant, determine the heat transfer per unit mass and the change in specific exergy, each in kJ/kg. Comment. Let \( T_0 = 20°C, p_0 = 0.1 \) MPa and ignore the effects of motion and gravity.

7.23 As shown in Fig. 7.23, two kilograms of water undergo a process from an initial state where the water is saturated vapor at 120°C, the velocity is 30 m/s, and the elevation is 6 m to a final state where the water is saturated liquid at 100°C, the velocity is 25 m/s, and the elevation is 3 m. Determine in kJ, (a) the exergy at the initial state, (b) the exergy at the final state, and (c) the change in exergy. Let \( T_0 = 25°C, p_0 = 1 \) atm, and \( g = 9.8 \) m/s².

7.24 Two pounds of air initially at 200°F and 50 lbm/in.² undergo two processes in series:

Process 1–2: Isothermal to \( T_2 = 10 \) lbm/in.²
Process 2–3: Constant pressure to \( T_3 = -10°F \)
(c) the change in exergy of the ammonia.
(d) the amount of exergy destruction.

Ignore the effects of motion and gravity and let \( T_0 = 60^\circ \text{F}, \ p_0 = 1 \ \text{atm} \).

As shown in Fig. P7.36, a 0.8-lb metal bar initially at 1900\(^\circ\)R is removed from an oven and quenched by immersing it in a closed tank containing 20 lb of water initially at 530\(^\circ\)R. Each substance can be modeled as incompressible. An appropriate constant specific heat for the water is \( c_w = 1.0 \ \text{Btu/lb} \cdot \text{R} \), and an appropriate value for the metal is \( c_m = 0.1 \ \text{Btu/lb} \cdot \text{R} \). Heat transfer from the tank contents can be neglected. Determine the exergy destruction, in Btu. Let \( T_0 = 77^\circ\)F.

One pound of air is contained in a closed, rigid, insulated tank. Initially the temperature is 500\(^\circ\)R and the pressure is 1 atm. The air is stirred by a paddle wheel until its temperature is 700\(^\circ\)R. Using the ideal gas model, determine for the air the change in exergy, the transfer of exergy accompanying work, and the exergy destruction, all in Btu. Ignore the effects of motion and gravity and let \( T_0 = 500^\circ \text{R}, \ p_0 = 1 \ \text{atm} \).

One kilogram of helium initially at 20\(^\circ\)C and 1 bar is contained within a rigid, insulated tank. The helium is stirred by a paddle wheel until its pressure is 1.45 bar. Employing the ideal gas model with \( k = 1.67 \), determine the work and the exergy destruction for the helium, each in kJ. Ignore the effects of motion and gravity and let \( T_0 = 20^\circ \text{C}, \ p_0 = 1 \ \text{bar} \).

One lbmol of carbon dioxide gas is contained in a 100-ft\(^3\) rigid, insulated vessel initially at 4 atm. An electric resistor of negligible mass transfers energy to the gas at a constant rate of 12 Btu/s for 1 min. Employing the ideal gas model and ignoring the effects of motion and gravity, determine (a) the change in exergy of the gas, (b) the electrical work, and (c) the exergy destruction, each in Btu. Let \( T_0 = 70^\circ \text{F}, \ p_0 = 1 \ \text{atm} \).

A rigid, well-insulated tank consists of two compartments, each having the same volume, separated by a valve. Initially, one of the compartments is evacuated and the other contains 0.25 lbmol of nitrogen gas at 50 lbfs/in\(^2\) and 100\(^\circ\)F. The valve is opened and the gas expands to fill the total volume, eventually achieving an equilibrium state. Using the ideal gas model for the nitrogen

(a) determine the final temperature, in \(^\circ\)F, and final pressure, in lbfs/in\(^2\).
(b) evaluate the exergy destruction, in Btu.
(c) What is the cause of exergy destruction in this case?

Let \( T_0 = 70^\circ \text{F}, \ p_0 = 1 \ \text{atm} \).

Figure P7.37 provides steady-state data for a composite of a hot plate and two solid layers. Perform a full exergy accounting, in kW, of the electrical power provided to the composite, including the exergy transfer accompanying heat transfer from the composite and the destruction of exergy in the hot plate and each of the two layers. Let \( T_0 = 300 \ \text{K} \).

As shown in Fig. P7.38, heat transfer at a rate of 500 Btu/h takes place through the inner surface of a wall. Measurements made during steady-state operation reveal temperatures of \( T_1 = 2500^\circ \text{R} \) and \( T_2 = 1000^\circ \text{R} \) at the inner and outer surfaces, respectively. Determine, in Btu/h

(a) the rates of exergy transfer accompanying heat at the inner and outer surfaces of the wall.
(b) the rate of exergy destruction.
(c) What is the cause of exergy destruction in this case?

Let \( T_0 = 500^\circ \text{R} \).