

- Q19.5** Thermal expansion of the glass bulb occurs first, since the wall of the bulb is in direct contact with the hot water. Then the mercury heats up, and it expands.
- Q19.12** At high temperature and pressure, the steam inside exerts large forces on the pot and cover. Strong latches hold them together, but they would explode apart if you tried to open the hot cooker.
- P19.11** For the dimensions to increase,  $\Delta L = \alpha L_i \Delta T$

$$1.00 \times 10^{-2} \text{ cm} = 1.30 \times 10^{-4} \text{ }^{\circ}\text{C}^{-1} (2.20 \text{ cm}) (T - 20.0 \text{ }^{\circ}\text{C})$$

$$T = \boxed{55.0 \text{ }^{\circ}\text{C}}$$

**P19.33**  $\sum F_y = 0: \rho_{\text{out}} g V - \rho_{\text{in}} g V - (200 \text{ kg}) g = 0$

$$(\rho_{\text{out}} - \rho_{\text{in}}) (400 \text{ m}^3) = 200 \text{ kg}$$

The density of the air outside is  $1.25 \text{ kg/m}^3$ .

From  $PV = nRT$ ,  $\frac{n}{V} = \frac{P}{RT}$

The density is inversely proportional to the temperature, and the density of the hot air is

$$\rho_{\text{in}} = (1.25 \text{ kg/m}^3) \left( \frac{283 \text{ K}}{T_{\text{in}}} \right)$$

Then  $(1.25 \text{ kg/m}^3) \left( 1 - \frac{283 \text{ K}}{T_{\text{in}}} \right) (400 \text{ m}^3) = 200 \text{ kg}$

$$1 - \frac{283 \text{ K}}{T_{\text{in}}} = 0.400$$

$$0.600 = \frac{283 \text{ K}}{T_{\text{in}}} \quad T_{\text{in}} = \boxed{472 \text{ K}}$$

**P19.38** At depth,  $P = P_0 + \rho gh$  and  $PV_i = nRT_i$

At the surface,  $P_0 V_f = nRT_f$ :  $\frac{P_0 V_f}{(P_0 + \rho gh)V_i} = \frac{T_f}{T_i}$

Therefore  $V_f = V_i \left( \frac{T_f}{T_i} \right) \left( \frac{P_0 + \rho gh}{P_0} \right)$

$$V_f = 1.00 \text{ m}^3 \left( \frac{293 \text{ K}}{278 \text{ K}} \right) \left( \frac{1.013 \times 10^5 \text{ Pa} + (1.025 \text{ kg/m}^3)(9.80 \text{ m/s}^2)(25.0 \text{ m})}{1.013 \times 10^5 \text{ Pa}} \right)$$

$$V_f = \boxed{3.67 \text{ m}^3}$$

**P19.58** (a)  $B = \rho g V'$   $P' = P_0 + \rho g d$   $P' V' = P_0 V_i$

$$B = \frac{\rho g P_0 V_i}{P'} = \boxed{\frac{\rho g P_0 V_i}{(P_0 + \rho g d)}}$$

(b) Since  $d$  is in the denominator,  $B$  must decrease as the depth increases.

(The volume of the balloon becomes smaller with increasing pressure.)

(c)  $\frac{1}{2} = \frac{B(d)}{B(0)} = \frac{\rho g P_0 V_i / (P_0 + \rho g d)}{\rho g P_0 V_i / P_0} = \frac{P_0}{P_0 + \rho g d}$

$$P_0 + \rho g d = 2P_0$$

$$d = \frac{P_0}{\rho g} = \frac{1.013 \times 10^5 \text{ N/m}^2}{(1.00 \times 10^3 \text{ kg/m}^3)(9.80 \text{ m/s}^2)} = \boxed{10.3 \text{ m}}$$

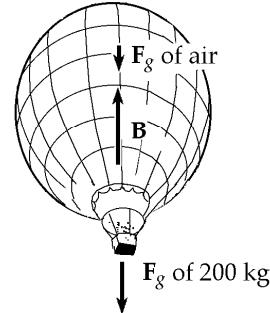
**P19.2** (a)  $1.06 \text{ atm}$ ; (b)  $-124 \text{ }^{\circ}\text{C}$

**P19.4** (a)  $37.0 \text{ }^{\circ}\text{C} = 310 \text{ K}$ ; (b)  $-20.5 \text{ }^{\circ}\text{C} = 253 \text{ K}$

**P19.6**  $T_C = (1.33 \text{ C}^{\circ}/\text{S}^{\circ})T_S + 20.0 \text{ }^{\circ}\text{C}$

**P19.8** 0.313 m

**P19.10** 1.20 cm



**FIG. P19.33**

**P19.12**  $15.8 \mu\text{m}$

**P19.14** 0.663 mm to the right at  $78.2^\circ$  below the horizontal

**P19.16** (a)  $0.109 \text{ cm}^2$ ; (b) increase

**P19.18** (a)  $437 \text{ }^{\circ}\text{C}$ ; (b)  $3000 \text{ }^{\circ}\text{C}$ ; no

- P19.20** (a)  $2.52 \times 10^6 \text{ N/m}^2$ ; (b) no  
**P19.22**  $0.812 \text{ cm}^3$   
**P19.24** (a) 396 N; (b)  $-101^\circ\text{C}$ ; (c) no change  
**P19.26** (a) 2.99 m ol; (b)  $1.80 \times 10^{24} \text{ molecules}$   
**P19.28** 884 balloons  
**P19.30** (a)  $1.06 \times 10^{21} \text{ kg}$ ; (b) 56.9 K  
**P19.32** (a) 900 K; (b) 1 200 K  
**P19.36**  $3.96 \times 10^{-2} \text{ mol}$   
**P19.38**  $3.67 \text{ cm}^3$   
**P19.40** between  $10^1 \text{ kg}$  and  $10^2 \text{ kg}$   
**P19.42**  $2.41 \times 10^{11} \text{ molecules}$   
**Q20.14** The materials used to make the support structure of the roof have a higher thermal conductivity than the insulated spaces in between. The heat from the barn conducts through the rafters and melts the snow.  
**Q20.29** The person should add the cream immediately when the coffee is poured. Then the smaller temperature difference between coffee and environment will reduce the rate of energy loss during the several minutes.  
**P20.17** The bullet will not melt all the ice, so its final temperature is  $0^\circ\text{C}$ .

$$\text{Then } \left( \frac{1}{2} m v^2 + m c |\Delta T| \right)_{\text{bullet}} = m_w L_f$$

where  $m_w$  is the melt water mass

$$m_w = \frac{0.500 (3.00 \times 10^{-3} \text{ kg}) (240 \text{ m/s})^2 + 3.00 \times 10^{-3} \text{ kg} (128 \text{ J/kg}\cdot^\circ\text{C}) (30.0^\circ\text{C})}{3.33 \times 10^5 \text{ J/kg}}$$

$$m_w = \frac{86.4 \text{ J} + 11.5 \text{ J}}{333\,000 \text{ J/kg}} = \boxed{0.294 \text{ g}}$$

$$\text{P20.26 } W = - \int_i^f P dV = -P \int_i^f dV = -P \Delta V = -nR \Delta T = \boxed{-nR(T_2 - T_1)}$$

**P20.43** In the steady state condition,  $P_{\text{Au}} = P_{\text{Ag}}$

$$\text{so that } k_{\text{Au}} A_{\text{Au}} \left( \frac{\Delta T}{\Delta x} \right)_{\text{Au}} = k_{\text{Ag}} A_{\text{Ag}} \left( \frac{\Delta T}{\Delta x} \right)_{\text{Ag}}$$

In this case

$$A_{\text{Au}} = A_{\text{Ag}}$$

$$\Delta x_{\text{Au}} = \Delta x_{\text{Ag}}$$

$$\Delta T_{\text{Au}} = (80.0 - T)$$

$$\text{and } \Delta T_{\text{Ag}} = (T - 30.0)$$

where  $T$  is the temperature of the junction.

$$\text{Therefore, } k_{\text{Au}} (80.0 - T) = k_{\text{Ag}} (T - 30.0)$$

$$\text{And } \boxed{T = 51.2^\circ\text{C}}$$

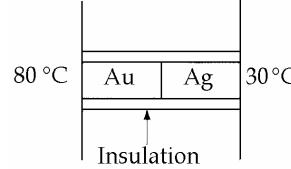
**P20.51** The sphere of radius  $R$  absorbs sunlight over the area of its day hemisphere, projected as a flat circle perpendicular to the light:  $\pi R^2$ . It radiates in all directions, over area  $4\pi R^2$ . Then, in steady state,

$$P_{\text{in}} = P_{\text{out}}$$

$$e (1340 \text{ W/m}^2) \pi R^2 = e \sigma (4\pi R^2) T^4$$

The emissivity  $e$ , the radius  $R$ , and  $\pi$  all cancel.

$$\text{Therefore, } T = \left[ \frac{1340 \text{ W/m}^2}{4(5.67 \times 10^{-8} \text{ W/m}^2 \cdot \text{K}^4)} \right]^{1/4} = \boxed{277 \text{ K}} = 4^\circ\text{C}.$$



**FIG. P20.43**

\***P20.61** The loss of mechanical energy is

$$\frac{1}{2} m v_i^2 + \frac{GM_E m}{R_E} = \frac{1}{2} 670 \text{ kg} (1.4 \times 10^4 \text{ m/s})^2 + \frac{6.67 \times 10^{-11} \text{ N m}^2}{\text{kg}^2} \frac{5.98 \times 10^{24} \text{ kg} 670 \text{ kg}}{6.37 \times 10^6 \text{ m}}$$

$$= 6.57 \times 10^{10} \text{ J} + 4.20 \times 10^{10} \text{ J} = 1.08 \times 10^{11} \text{ J}$$

One half becomes extra internal energy in the aluminum:  $\Delta E_{\text{int}} = 5.38 \times 10^{10} \text{ J}$ . To raise its temperature to the melting point requires energy

$$m c \Delta T = 670 \text{ kg } 900 \frac{\text{J}}{\text{kg}^\circ\text{C}} (660 - (-15^\circ\text{C})) = 4.07 \times 10^8 \text{ J.}$$

To melt it,  $m L = 670 \text{ kg } 3.97 \times 10^5 \text{ J/kg} = 2.66 \times 10^8 \text{ J}$ . To raise it to the boiling point,

$$m c \Delta T = 670(1170)(2450 - 600) = 1.40 \times 10^9 \text{ J.}$$

$$5.38 \times 10^{10} \text{ J} = 9.71 \times 10^9 \text{ J} + 670(1170)(T_f - 2450^\circ\text{C}) \text{ J}/^\circ\text{C}$$

$$T_f = \boxed{5.87 \times 10^4 \text{ C}}$$

**P20.2**  $0.105^\circ\text{C}$

**P20.4**  $87.0^\circ\text{C}$

**P20.6** The energy input to the water is 6.70 times larger than the laser output of 40.0 kJ.

**P20.8**  $88.2 \text{ W}$

**P20.10** (a)  $25.8^\circ\text{C}$ ; (b) no

$$\boxed{T_f = \frac{(m_{A1}C_{A1} + m_c C_w)T_c + m_h C_w T_h}{m_{A1}C_{A1} + m_c C_w + m_h C_w}}$$

**P20.14** (a)  $380 \text{ K}$ ; (b)  $206 \text{ kPa}$

**P20.16**  $12.9 \text{ g}$

**P20.18** (a) all the ice melts;  $40.4^\circ\text{C}$ ;

(b)  $8.04 \text{ g}$  melts;  $0^\circ\text{C}$

**P20.20**  $34.0 \text{ km}$

**P20.22** liquid lead at  $805^\circ\text{C}$

**P20.24** (a)  $-12.0 \text{ M J}$ ; (b)  $+12.0 \text{ M J}$

**P20.26**  $-nR(T_2 - T_1)$

**P20.28** (a)  $567 \text{ J}$ ; (b)  $167 \text{ J}$

**P20.30** (a)  $12.0 \text{ kJ}$ ; (b)  $-12.0 \text{ kJ}$

**P20.32**  $42.9 \text{ kJ}$

**P20.34** (a)  $7.65 \text{ L}$ ; (b)  $305 \text{ K}$

**P20.36** (a)  $-48.6 \text{ m J}$ ; (b)  $16.2 \text{ kJ}$ ; (c)  $16.2 \text{ kJ}$

**P20.38** (a)  $-4P_i V_i$ ; (b)  $+4P_i V_i$ ; (c)  $-9.08 \text{ kJ}$

**P20.40** (a)  $1300 \text{ J}$ ; (b)  $100 \text{ J}$ ; (c)  $-900 \text{ J}$ ; (d)  $-1400 \text{ J}$

**P20.42**  $10.0 \text{ kW}$

**P20.44**  $1.34 \text{ kW}$

**Q21.5** The alcohol evaporates, absorbing energy from the skin to lower the skin temperature.

$$\boxed{F = \frac{(5.00 \times 10^{23})(2(4.68 \times 10^{-26} \text{ kg})(300 \text{ m/s})}{1.00 \text{ s}} = 14.0 \text{ N}}$$

$$\text{and } P = \frac{\bar{F}}{A} = \frac{14.0 \text{ N}}{8.00 \times 10^{-4} \text{ m}^2} = \boxed{17.6 \text{ kPa}}.$$

**P21.24** (a)  $P_i V_i^\gamma = P_f V_f^\gamma$  so

$$\frac{V_f}{V_i} = \left( \frac{P_i}{P_f} \right)^{1/\gamma} = \left( \frac{1.00}{20.0} \right)^{5/7} = \boxed{0.118}$$

$$(b) \frac{T_f}{T_i} = \frac{P_f V_f}{P_i V_i} = \left( \frac{P_f}{P_i} \right) \left( \frac{V_f}{V_i} \right) = (20.0)(0.118)$$

$$\frac{T_f}{T_i} = \boxed{2.35}$$

(c) Since the process is adiabatic,

$$\boxed{Q = 0}$$

$$\text{Since } \gamma = 1.40 = \frac{C_p}{C_v} = \frac{R + C_v}{C_v},$$

$$C_v = \frac{5}{2} R \text{ and } \Delta T = 2.35 T_i - T_i = 1.35 T_i$$

$$\Delta E_{\text{int}} = n C_v \Delta T = (0.0160 \text{ mol}) \left( \frac{5}{2} \right) (8.314 \text{ J/mol K}) [1.35(300 \text{ K})] = \boxed{135 \text{ J}}$$

$$\text{and } \boxed{W = -Q + \Delta E_{\text{int}} = 0 + 135 \text{ J}}.$$

**P20.46** (a)  $0.890 \text{ ft}^2 \cdot {}^\circ\text{F} \cdot \text{h/Btu}$ ; (b)  $1.85 \frac{\text{ft}^2 \cdot {}^\circ\text{F} \cdot \text{h}}{\text{Btu}}$ ; (c)  $2.08$

**P20.48** (a)  $\sim 10^3 \text{ W}$ ; (b)  $\sim -10^{-1} \text{ K/s}$

**P20.50**  $364 \text{ K}$

**P20.52**  $47.7 \text{ g}$

**P20.54** (a)  $13.0^\circ\text{C}$ ; (b)  $-0.532^\circ\text{C/s}$

**P20.56** (a)  $64.1^\circ\text{C}$ ; (b)  $113^\circ\text{C}$

**P20.58** see the solution (a)  $\frac{1}{2} P_i V_i$ ; (b)  $1.39 P_i V_i$ ; (c)  $0$

**P20.60** (a)  $9.31 \times 10^{10} \text{ J}$ ; (b)  $-8.47 \times 10^{12} \text{ J}$ ; (c)  $8.38 \times 10^{12} \text{ J}$

**P20.62** (a)  $2000 \text{ W}$ ; (b)  $4.47^\circ\text{C}$

**P20.64**  $3.76 \text{ m/s}$

**P20.66** (a)  $15.0 \text{ m g}$ ; block:  $Q = 0$ ;  $W = -5.00 \text{ J}$ ;  $\Delta E_{\text{int}} = 0$ ;  $\Delta K = -5.00 \text{ J}$ ; ice:  $Q = 0$ ;  $W = 5.00 \text{ J}$ ;  $\Delta E_{\text{int}} = 5.00 \text{ J}$ ;  $\Delta K = 0$

(b)  $15.0 \text{ m g}$ ; block:  $Q = 0$ ;  $W = 0$ ;  $\Delta E_{\text{int}} = 5.00 \text{ J}$ ;

$\Delta K = -5.00 \text{ J}$ ; metal:  $Q = 0$ ;  $W = 0$ ;  $\Delta E_{\text{int}} = 0$ ;

$\Delta K = 0$  (c)  $0.00404^\circ\text{C}$ ; moving block:  $Q = 0$ ;

$W = -2.50 \text{ J}$ ;  $\Delta E_{\text{int}} = 2.50 \text{ J}$ ;

$\Delta K = -5.00 \text{ J}$ ; stationary block:  $Q = 0$ ;  $W = 2.50 \text{ J}$ ;

$\Delta E_{\text{int}} = 2.50 \text{ J}$ ;  $\Delta K = 0$

**P20.68**  $10.2 \text{ h}$

**P20.72**  $800 \text{ J/kg} \cdot {}^\circ\text{C}$

**P21.26**  $V_i = \pi \left( \frac{2.50 \times 10^{-2} \text{ m}}{2} \right)^2 0.500 \text{ m} = 2.45 \times 10^{-4} \text{ m}^3$

The quantity of air we find from  $P_i V_i = n R T_i$

$$n = \frac{P_i V_i}{R T_i} = \frac{(1.013 \times 10^5 \text{ Pa})(2.45 \times 10^{-4} \text{ m}^3)}{(8.314 \text{ J/m ol K})(300 \text{ K})}$$

$$n = 9.97 \times 10^{-3} \text{ mol}$$

Adiabatic compression:  $P_f = 101.3 \text{ kPa} + 800 \text{ kPa} = 901.3 \text{ kPa}$

(a)  $P_i V_i^\gamma = P_f V_f^\gamma$

$$V_f = V_i \left( \frac{P_i}{P_f} \right)^{1/\gamma} = 2.45 \times 10^{-4} \text{ m}^3 \left( \frac{101.3}{901.3} \right)^{5/7}$$

$$V_f = \boxed{5.15 \times 10^{-5} \text{ m}^3}$$

(b)  $P_f V_f = n R T_f$

$$T_f = T_i \frac{P_f V_f}{P_i V_i} = T_i \frac{P_f}{P_i} \left( \frac{P_i}{P_f} \right)^{1/\gamma} = T_i \left( \frac{P_i}{P_f} \right)^{(1/\gamma)-1}$$

$$T_f = 300 \text{ K} \left( \frac{101.3}{901.3} \right)^{(5/7)-1} = \boxed{560 \text{ K}}$$

(c) The work put into the gas in compressing it is  $\Delta E_{\text{int}} = n C_V \Delta T$

$$W = (9.97 \times 10^{-3} \text{ mol}) \frac{5}{2} (8.314 \text{ J/m ol K}) (560 - 300) \text{ K}$$

$$W = 53.9 \text{ J}$$

Now imagine this energy being shared with the inner wall as the gas is held at constant volume. The pump wall has outer diameter  $25.0 \text{ mm} + 2.00 \text{ mm} + 2.00 \text{ mm} = 29.0 \text{ mm}$ , and volume

$$\left[ \pi (14.5 \times 10^{-3} \text{ m})^2 - \pi (12.5 \times 10^{-3} \text{ m})^2 \right] 4.00 \times 10^{-2} \text{ m} = 6.79 \times 10^{-6} \text{ m}^3$$

and mass  $\rho V = (7.86 \times 10^3 \text{ kg/m}^3)(6.79 \times 10^{-6} \text{ m}^3) = 53.3 \text{ g}$

The overall warming process is described by

$$53.9 \text{ J} = n C_V \Delta T + m c \Delta T$$

$$53.9 \text{ J} = (9.97 \times 10^{-3} \text{ mol}) \frac{5}{2} (8.314 \text{ J/m ol K}) (T_{\text{ff}} - 300 \text{ K})$$

$$+ (53.3 \times 10^{-3} \text{ kg}) (448 \text{ J/kg K}) (T_{\text{ff}} - 300 \text{ K})$$

$$53.9 \text{ J} = (0.207 \text{ J/K} + 23.9 \text{ J/K}) (T_{\text{ff}} - 300 \text{ K})$$

$$T_{\text{ff}} - 300 \text{ K} = \boxed{2.24 \text{ K}}$$

**P21.41** (a) From  $v_{\text{av}} = \sqrt{\frac{8k_B T}{\pi m}}$

we find the temperature as  $T = \frac{\pi (6.64 \times 10^{-27} \text{ kg}) (1.12 \times 10^4 \text{ m/s})^2}{8 (1.38 \times 10^{-23} \text{ J/m ol K})} = \boxed{2.37 \times 10^4 \text{ K}}$

(b)  $T = \frac{\pi (6.64 \times 10^{-27} \text{ kg}) (2.37 \times 10^3 \text{ m/s})^2}{8 (1.38 \times 10^{-23} \text{ J/m ol K})} = \boxed{1.06 \times 10^3 \text{ K}}$

**P21.2** 17.6 kPa

**P21.4**  $5.05 \times 10^{-21} \text{ J/m molecule}$

**P21.6**  $6.64 \times 10^{-27} \text{ kg}$

**P21.8** 477 m/s

**P21.10** (a) 2.28 kJ; (b)  $6.21 \times 10^{-21} \text{ J}$

**P21.12** 74.8 J

**P21.14** 7.52 L

**P21.16** (a) 118 kJ; (b)  $6.03 \times 10^3 \text{ kg}$

**P21.18** (a) 719 J/kg K; (b) 0.811 kg; (c) 233 kJ;

(d) 327 kJ

**P21.20** 13.5 PV

**P21.22** (a)  $4T_i$ ; (b)  $9(1 \text{ mol}) RT_i$

**P21.24** (a) 0.118; (b) 2.35; (c) 0; 135 J; 135 J

**P21.26** (a)  $5.15 \times 10^{-5} \text{ m}^3$ ; (b) 560 K; (c) 2.24 K

**P21.28** (a) 1.55; (b)  $0.127 \text{ m}^3$

**P21.30** (b)  $2.19V_i$ ; (c)  $3T_i$ ; (d)  $T_i$ ; (e)  $-0.830PV_i$

**P21.32** 25.0 kW

**P21.36** (a) No atom, almost all the time; (b)  $2.70 \times 10^{20}$

**Q22.7** Suppose the ambient temperature is 20°C. A gas can be heated to the temperature of the bottom of the pond, and allowed to cool as it blows through a turbine. The Carnot efficiency of such an engine is about

$$e_c = \frac{\Delta T}{T_h} = \frac{80}{373} = 22\% .$$

**\*P22.5** (a) The input energy each hour is

$$(7.89 \times 10^3 \text{ J/revolution}) (2500 \text{ rev/m in}) \frac{60 \text{ m in}}{1 \text{ h}} = 1.18 \times 10^9 \text{ J/h}$$

$$\text{implying fuel input } (1.18 \times 10^9 \text{ J/h}) \left( \frac{1 \text{ L}}{4.03 \times 10^7 \text{ J}} \right) = [29.4 \text{ L/h}]$$

(b)  $Q_h = W_{\text{eng}} + |Q_c|$ . For a continuous-transfer process we may divide by time to have

$$\frac{Q_h}{\Delta t} = \frac{W_{\text{eng}}}{\Delta t} + \frac{|Q_c|}{\Delta t}$$

$$\text{useful power output} = \frac{W_{\text{eng}}}{\Delta t} = \frac{Q_h}{\Delta t} - \frac{|Q_c|}{\Delta t}$$

$$= \left( \frac{7.89 \times 10^3 \text{ J}}{\text{revolution}} - \frac{4.58 \times 10^3 \text{ J}}{\text{revolution}} \right) \frac{2500 \text{ rev}}{1 \text{ m in}} \frac{1 \text{ m in}}{60 \text{ s}} = 1.38 \times 10^5 \text{ W}$$

$$P_{\text{eng}} = 1.38 \times 10^5 \text{ W} \left( \frac{1 \text{ hp}}{746 \text{ W}} \right) = [185 \text{ hp}]$$

(c)  $P_{\text{eng}} = \tau \omega \Rightarrow \tau = \frac{P_{\text{eng}}}{\omega} = \frac{1.38 \times 10^5 \text{ J/s}}{(2500 \text{ rev}/60 \text{ s})} \left( \frac{1 \text{ rev}}{2\pi \text{ rad}} \right) = [527 \text{ N} \cdot \text{m}]$

(d)  $\frac{|Q_c|}{\Delta t} = \frac{4.58 \times 10^3 \text{ J}}{\text{revolution}} \left( \frac{2500 \text{ rev}}{60 \text{ s}} \right) = [1.91 \times 10^5 \text{ W}]$

**P22.11**  $T_c = 703 \text{ K}$      $T_h = 2143 \text{ K}$

(a)  $e_c = \frac{\Delta T}{T_h} = \frac{1440}{2143} = [67.2\%]$

(b)  $|Q_h| = 1.40 \times 10^5 \text{ J}$ ,  $W_{\text{eng}} = 0.420|Q_h|$

$$P = \frac{W_{\text{eng}}}{\Delta t} = \frac{5.88 \times 10^4 \text{ J}}{1 \text{ s}} = [58.8 \text{ kW}]$$

**P22.21** For the Carnot engine,  $e_c = 1 - \frac{T_c}{T_h} = 1 - \frac{300 \text{ K}}{750 \text{ K}} = 0.600$ .

Also,  $e_c = \frac{W_{\text{eng}}}{|Q_h|}$ .

so  $|Q_h| = \frac{W_{\text{eng}}}{e_c} = \frac{150 \text{ J}}{0.600} = 250 \text{ J}$ .

and  $|Q_c| = |Q_h| - W_{\text{eng}} = 250 \text{ J} - 150 \text{ J} = 100 \text{ J}$

(a)  $|Q_h| = \frac{W_{\text{eng}}}{e_s} = \frac{150 \text{ J}}{0.700} = [214 \text{ J}]$

$$|Q_c| = |Q_h| - W_{\text{eng}} = 214 \text{ J} - 150 \text{ J} = [64.3 \text{ J}]$$

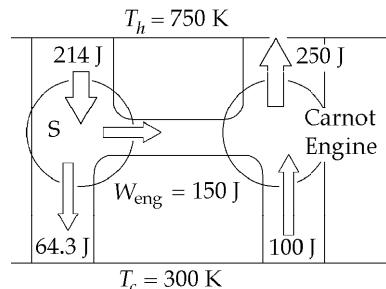
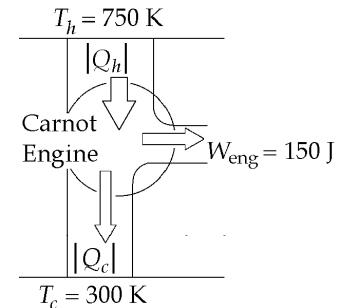
(b)  $|Q_{h,\text{net}}| = 214 \text{ J} - 250 \text{ J} = [-35.7 \text{ J}]$

$$|Q_{c,\text{net}}| = 64.3 \text{ J} - 100 \text{ J} = [-35.7 \text{ J}]$$

The net flow of energy by heat from the cold to the hot reservoir without work input, is impossible.

**P21.38** (a) 1.03; (b)  $^{35}\text{Cl}$

**P21.40** 132 m/s

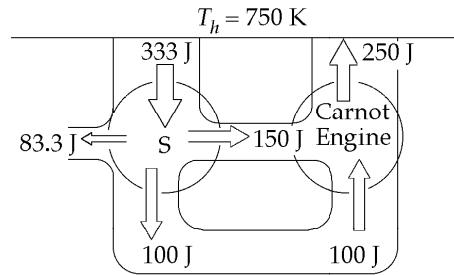


**FIG. P22.21(b)**

(c) For engine S:  $|Q_c| = |Q_h| - W_{eng} = \frac{W_{eng}}{e_S} - W_{eng}$ . so  $W_{eng} = \frac{|Q_c|}{\frac{1}{e_S} - 1} = \frac{100 \text{ J}}{\frac{1}{0.700} - 1} = \boxed{233 \text{ J}}$ .  
and  $|Q_h| = |Q_c| + W_{eng} = 233 \text{ J} + 100 \text{ J} = \boxed{333 \text{ J}}$ .

(d)  $|Q_{h,net}| = 333 \text{ J} - 250 \text{ J} = \boxed{83.3 \text{ J}}$   
 $W_{net} = 233 \text{ J} - 150 \text{ J} = \boxed{83.3 \text{ J}}$   
 $|Q_{c,net}| = \boxed{0}$

The output of 83.3 J of energy from the heat engine by work in a cyclic process without any exhaust by heat is impossible.



(e) Both engines operate in cycles, so  $\Delta S_S = \Delta S_{Carnot} = 0$ .

For the reservoirs,  $\Delta S_h = -\frac{|Q_h|}{T_h}$  and  $\Delta S_c = +\frac{|Q_c|}{T_c}$ .

Thus,  $\Delta S_{total} = \Delta S_S + \Delta S_{Carnot} + \Delta S_h + \Delta S_c = 0 + 0 - \frac{83.3 \text{ J}}{750 \text{ K}} + \frac{0}{300 \text{ K}} = \boxed{-0.111 \text{ J/K}}$ .

A decrease in total entropy is impossible.

P22.34 (a), (b) The quantity of gas is

$$n = \frac{P_A V_A}{RT_A} = \frac{(100 \times 10^3 \text{ Pa})(500 \times 10^{-6} \text{ m}^3)}{(8.314 \text{ J/m ol.K})(293 \text{ K})} = 0.0205 \text{ m ol}$$

$$E_{int,A} = \frac{5}{2} nRT_A = \frac{5}{2} P_A V_A = \frac{5}{2} (100 \times 10^3 \text{ Pa})(500 \times 10^{-6} \text{ m}^3) = \boxed{125 \text{ J}}$$

In process AB,  $P_B = P_A \left( \frac{V_A}{V_B} \right)^{\gamma} = (100 \times 10^3 \text{ Pa}) (8.00)^{1.40} = \boxed{1.84 \times 10^6 \text{ Pa}}$

$$T_B = \frac{P_B V_B}{nR} = \frac{(1.84 \times 10^6 \text{ Pa})(500 \times 10^{-6} \text{ m}^3 / 8.00)}{(0.0205 \text{ m ol})(8.314 \text{ J/m ol.K})} = \boxed{673 \text{ K}}$$

$$E_{int,B} = \frac{5}{2} nRT_B = \frac{5}{2} (0.0205 \text{ m ol})(8.314 \text{ J/m ol.K})(673 \text{ K}) = \boxed{287 \text{ J}}$$

so  $\Delta E_{int,AB} = 287 \text{ J} - 125 \text{ J} = \boxed{162 \text{ J}} = Q - W_{out} = 0 - W_{out}$   $W_{AB} = \boxed{-162 \text{ J}}$

Process BC takes us to:

$$P_C = \frac{nRT_C}{V_C} = \frac{(0.0205 \text{ m ol})(8.314 \text{ J/m ol.K})(1023 \text{ K})}{62.5 \times 10^{-6} \text{ m}^3} = \boxed{2.79 \times 10^6 \text{ Pa}}$$

$$E_{int,C} = \frac{5}{2} nRT_C = \frac{5}{2} (0.0205 \text{ m ol})(8.314 \text{ J/m ol.K})(1023 \text{ K}) = \boxed{436 \text{ J}}$$

$$E_{int,BC} = 436 \text{ J} - 287 \text{ J} = \boxed{149 \text{ J}} = Q - W_{out} = Q - 0$$

$$Q_{BC} = \boxed{149 \text{ J}}$$

In process CD:

$$P_D = P_C \left( \frac{V_C}{V_D} \right)^{\gamma} = (2.79 \times 10^6 \text{ Pa}) \left( \frac{1}{8.00} \right)^{1.40} = \boxed{1.52 \times 10^5 \text{ Pa}}$$

$$T_D = \frac{P_D V_D}{nR} = \frac{(1.52 \times 10^5 \text{ Pa})(500 \times 10^{-6} \text{ m}^3)}{(0.0205 \text{ m ol})(8.314 \text{ J/m ol.K})} = \boxed{445 \text{ K}}$$

$$E_{int,D} = \frac{5}{2} nRT_D = \frac{5}{2} (0.0205 \text{ m ol})(8.314 \text{ J/m ol.K})(445 \text{ K}) = \boxed{190 \text{ J}}$$

$$\Delta E_{int,CD} = 190 \text{ J} - 436 \text{ J} = \boxed{-246 \text{ J}} = Q - W_{out} = 0 - W_{out}$$

$$W_{CD} = \boxed{246 \text{ J}}$$

and  $\Delta E_{\text{int},DA} = E_{\text{int},A} - E_{\text{int},D} = 125 \text{ J} - 190 \text{ J} = \boxed{-65.0 \text{ J}} = Q - W_{\text{out}} = Q - 0$

$$Q_{DA} = \boxed{-65.0 \text{ J}}$$

For the entire cycle,  $\Delta E_{\text{int,net}} = 162 \text{ J} + 149 - 246 - 65.0 = \boxed{0}$ . The net work is

$$W_{\text{eng}} = -162 \text{ J} + 0 + 246 \text{ J} + 0 = \boxed{84.3 \text{ J}}$$

$$Q_{\text{net}} = 0 + 149 \text{ J} + 0 - 65.0 \text{ J} = \boxed{84.3 \text{ J}}$$

The tables look like:

State	$T(\text{K})$	$P(\text{kPa})$	$V(\text{cm}^3)$	$E_{\text{int}}(\text{J})$
A	293	100	500	125
B	673	1840	62.5	287
C	1023	2790	62.5	436
D	445	152	500	190
A	293	100	500	125

Process	$Q(\text{J})$	output $W(\text{J})$	$\Delta E_{\text{int}}(\text{J})$
AB	0	-162	162
BC	149	0	149
CD	0	246	-246
DA	-65.0	0	-65.0
ABCDA	84.3	84.3	0

- (c) The input energy is  $Q_h = \boxed{149 \text{ J}}$ , the waste is  $|Q_c| = \boxed{65.0 \text{ J}}$ , and  $W_{\text{eng}} = \boxed{84.3 \text{ J}}$ .
- (d) The efficiency is:  $e = \frac{W_{\text{eng}}}{Q_h} = \frac{84.3 \text{ J}}{149 \text{ J}} = \boxed{0.565}$ .
- (e) Let  $f$  represent the angular speed of the crankshaft. Then  $\frac{f}{2}$  is the frequency at which we obtain work in the amount of 84.3 J/cycle:

**P22.2** (a) 667 J; (b) 467 J

(d) -6.87 J/K ; (e) +9.16 J/K

**P22.4** (a) 30.0% ; (b) 60.0%

**P22.46** 0.507 J/K

**P22.6** 55.4%

**P22.48** 34.6 J/K

**P22.8** 77.8 W

**P22.50** (a) 2 heads and 2 tails ; (b) All heads or all tails;  
(c) 2 heads and 2 tails

**P22.10** (a) 869 M J; (b) 330 M J

**P22.52** 8.36 M J/K

**P22.12** 197 kJ

**P22.54** 32.9 kJ

**P22.14** 546°C

**P22.58** (a)  $2.62 \times 10^3$  tons/d ; (b) \$7.65 million/yr;  
(c)  $4.06 \times 10^4$  kg/s

**P22.16** 33.0%

**P22.60**  $\frac{P T_c}{(T_h - T_c) c \Delta T}$

**P22.18** (a) 5.12% ; (b) 5.27 TJ/h;

**P22.62** (a) 4.11 kJ; (b) 14.2 kJ; (c) 10.1 kJ; (d) 28.9%

**P22.20** 453 K

**P22.66**  $nC_p \ln 3$

**P22.22** (c) 23.7% ; see the solution

**P22.68** no; see the solution

**P22.24** 11.8

(a)	$P, \text{atm}$	$V, \text{L}$
A	25.0	1.97
B	4.14	11.9
C	1.00	32.8
D	6.03	5.44

**P22.34** (c)  $Q_h = 149 \text{ J}$ ;  $|Q_c| = 65.0 \text{ J}$ ;  $W_{\text{eng}} = 84.3 \text{ J}$ ;

(b) 2.99 kJ; (c) 33.3%

(d) 56.5%; (e)  $1.42 \times 10^3$  rev/m in

**P22.36** 4.88 kJ/kg·K

**P22.38** (a) isobaric; (b) 402 kJ; (c) 1.20 kJ/K

**P22.40** 3.27 J/K

**P22.42** 718 J/K

**P22.44** (a) 39.4 L ; (b) -2.50 kJ; (c) -2.50 kJ;