(20.1) A diesel engine performs 2200 J of mechanical work and discards 4300 J of heat each cycle. (a) How much heat must be supplied to the engine in each cycle? (b) What is the thermal efficiency of the engine?

(20.9) A refrigerator has a coefficient of performance of 2.10. In each cycle it absorbs 3.40E4 J of heat from the cold reservoir. (a) How much mechanical energy is required each cycle to operate the refrigerator? (b) During each cycle, how much heat is discarded to the high-temperature reservoir?

(20.13) A Carnot engine whose high-temperature reservoir is at 620 K takes in 550 J of heat at this temperature in each cycle and gives up 335 J to the low-temperature reservoir. (a) How much mechanical work does the engine perform during each cycle? (b) What is the temperature of the low-temperature reservoir? (c) What is the thermal efficiency of the cycle?

(20.16) An ice-making machine operates in a Carnot cycle. It takes heat from water at 0.0°C and rejects heat to a room at 24.0°C. Suppose that 85.0 kg of water at 0.0°C are converted to ice at 0.0°C. (a) How much heat is discharged into the room? (b) How much energy much be supplied to the device?

3. A block is placed near the edge of a horizontal turntable of radius 5 m that is initially at rest. It is attached to a motor that gives it an angular acceleration $\alpha$. The coefficient of static friction between the block and the turntable is $\mu_s = 0.2$. What is the maximum magnitude of the angular acceleration, $\alpha$, that the motor can deliver so that the block will not slide the instant after the turntable begins to move?
20.1. **IDENTIFY:** For a heat engine, \( W = |Q_H| - |Q_C| \). \( e = \frac{W}{Q_H} \). \( Q_H > 0 \), \( Q_C < 0 \).

**SET UP:** \( W = 2200 \text{ J} \), \( |Q_C| = 4300 \text{ J} \).

**EXECUTE:**

(a) \( Q_H = W + |Q_C| = 6500 \text{ J} \).

(b) \( e = \frac{2200 \text{ J}}{6500 \text{ J}} = 0.34 = 34\% \).

**EVALUATE:** Since the engine operates on a cycle, the net \( Q \) equal the net \( W \). But to calculate the efficiency we use the heat energy input, \( Q_H \).

20.9. **IDENTIFY** and **SET UP:** For the refrigerator \( K = 2.10 \) and \( Q_C = -3.4 \times 10^4 \text{ J} \). Use Eq.(20.9) to calculate \( |W| \) and then Eq.(20.2) to calculate \( Q_H \).

(a) **EXECUTE:** Performance coefficient \( K = \frac{Q_C}{|W|} \) (Eq.20.9)

\[
|W| = \frac{Q_C}{K} = \frac{3.4 \times 10^4 \text{ J}}{2.10} = 1.62 \times 10^4 \text{ J}
\]

(b) **SET UP:** The operation of the device is illustrated in Figure 20.9.

![Figure 20.9](image)

**EVALUATE** \( |Q_H| = |W| + |Q_C| \). The heat \( |Q_H| \) delivered to the high temperature reservoir is greater than the heat taken in from the low temperature reservoir.

20.13. **IDENTIFY:** Use Eq.(20.2) to calculate \( |W| \). Since it is a Carnot device we can use Eq.(20.13) to relate the heat flows out of the reservoirs. The reservoir temperatures can be used in Eq.(20.14) to calculate \( e \).

(a) **SET UP:** The operation of the device is sketched in Figure 20.13.

![Figure 20.13](image)

**EXECUTE:**

\( W = Q_C + Q_H \)

\( Q_H = W - Q_C \)

\( Q_H = -1.62 \times 10^4 \text{ J} - 3.40 \times 10^4 \text{ J} = -5.02 \times 10^4 \text{ J} \)

(negative because heat goes out of the system)

(b) For a Carnot cycle, \( \frac{|Q_C|}{|Q_H|} = \frac{T_C}{T_H} \) (Eq.20.13)

\[
T_C = T_H \frac{|Q_C|}{|Q_H|} = 620 \text{ K} \left( \frac{335 \text{ J}}{550 \text{ J}} \right) = 378 \text{ K}
\]

(c) \( e(\text{Carnot}) = 1 - T_C / T_H = 1 - 378 \text{ K}/620 \text{ K} = 0.390 = 39.0\% \)

**EVALUATE:** We could use the underlying definition of \( e \) (Eq.20.4):

\( e = \frac{W}{Q_H} = \frac{(215 \text{ J})/(550 \text{ J})}{39\%} \), which checks.
20.16. IDENTIFY and SET UP: The device is a Carnot refrigerator. We can use Eqs (20.2) and (20.13). (a) The operation of the device is sketched in Figure 20.16.

![Figure 20.16](image)

\[ \begin{align*}
Q_H &= 0 \\
Q_C &= +2.84 \times 10^7 \text{ J} \\
T_E &= 24.0^\circ \text{C} = 297 \text{ K} \\
T_R &= 0.0^\circ \text{C} = 273 \text{ K}
\end{align*} \]

**Figure 20.16**

The amount of heat taken out of the water to make the liquid → solid phase change is

\[ Q = -mL_f = -(8.5 \text{ kg})(334 \times 10^3 \text{ J/kg}) = -2.84 \times 10^7 \text{ J} \]  
This amount of heat must go into the working substance of the refrigerator, so \( Q_c = +2.84 \times 10^7 \text{ J} \). For Carnot cycle \( |Q_{E}|/|Q_{R}| = T_E/T_R \)

**EXECUTE:**

\[ W = 0 - Q_C = -2.84 \times 10^7 \text{ J} - 5.09 \times 10^7 \text{ J} = -2.5 \times 10^7 \text{ J} \]

**EVALUATE:** \( W \) is negative because this much energy must be supplied to the refrigerator rather than obtained from it. Note that in Eq (20.13) we must use Kelvin temperatures.

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3. \[ r = 5 \text{ m}, \omega = 0 \text{ rad/s}, \theta_s = 0.2, \alpha_{\text{max}} = ? \]

\[ \Sigma F_x = \max = (f_x)_{\max} = \mu_s N = \mu_s mg \]

\[ \alpha = \omega_{\text{tan}} = r\alpha \quad (a_{\text{rot}} = r\omega^2 = 0) \]

\[ \Rightarrow \max = \mu_s mg \]

\[ \alpha = \frac{\mu_s g}{r} = \frac{(0.2)(9.8) \text{ m/s}^2}{5 \text{ m}} = 0.392 \text{ rad/s} \]