Efficiency

The **efficiency**, e, of any heat engine can be defined as the ratio of the work it does, W, to the heat input at the high temperature, Q_H (Fig. 15–11):

$$e = \frac{W}{Q_H}.$$

This is a sensible definition since W is the output (what you get from the engine), whereas Q_H is what you put in and pay for in burned fuel. Since energy is conserved, the heat input Q_H must equal the work done plus the heat that flows out at the low temperature (Q_L):

$$Q_H = W + Q_L.$$

Thus $W = Q_H - Q_L$, and the efficiency of an engine is

Efficiency of any heat engine

$$e = \frac{W}{Q_H} \quad \textbf{(15–4a)}$$

$$= \frac{Q_H - Q_L}{Q_H} = 1 - \frac{Q_L}{Q_H}. \quad \textbf{(15–4b)}$$

To give the efficiency as a percent, we multiply Eq. 15–4 by 100. Note that e could be 1.0 (or 100%) only if Q_L were zero—that is, only if no heat were exhausted to the environment.

EXAMPLE 15–9 **Car efficiency.** An automobile engine has an efficiency of 20% and produces an average of 23,000 J of mechanical work per second during operation. (*a*) How much heat input is required, and (*b*) how much heat is discharged as waste heat from this engine, per second?

APPROACH We want to find the heat input Q_H as well as the heat output Q_L, given $W = 23{,}000$ J each second and an efficiency $e = 0.20$. We can use the definition of efficiency, Eq. 15–4 in its various forms, to find first Q_H and then Q_L.

SOLUTION (*a*) From Eq. 15–4, $e = W/Q_H$, we solve for Q_H:

$$Q_H = \frac{W}{e} = \frac{23{,}000\text{ J}}{0.20}$$

$$= 1.15 \times 10^5\text{ J} = 115\text{ kJ}.$$

The engine requires $115\text{ kJ/s} = 115\text{ kW}$ of heat input.

(*b*) We now use the last part of Eq. 15–4 $(e = 1 - Q_L/Q_H)$ to solve for Q_L:

$$\frac{Q_L}{Q_H} = 1 - e$$

so

$$Q_L = (1 - e)Q_H = (0.80)115\text{ kJ}$$

$$= 92\text{ kJ}.$$

The engine discharges heat to the environment at a rate of $92\text{ kJ/s} = 92\text{ kW}$.

NOTE Of the 115 kJ that enters the engine per second, only 23 kJ does useful work whereas 92 kJ is wasted as heat output.

NOTE The problem was stated in terms of energy per unit time. We could just as well have stated it in terms of power, since $1\text{ J/s} = 1\text{ W}$.