SECTION 3

The Second Law of Thermodynamics

SECTION OBJECTIVES

- **Recognize why the second law of thermodynamics requires two bodies at different temperatures for work to be done.**
- **Calculate the efficiency of a heat engine.**
- **Relate the disorder of a system to its ability to do work or transfer energy as heat.**

EFFICIENCY OF HEAT ENGINES

In the previous section, you learned how a heat engine absorbs a quantity of energy from a high-temperature body as heat, does work on the environment, and then gives up energy to a low-temperature body as heat. The work derived from each cycle of a heat engine equals the difference between the heat input and heat output during the cycle, as follows:

$$W_{net} = Q_{net} = Q_h - Q_c$$

This equation, obtained from the first law of thermodynamics, indicates that all energy entering and leaving the system is accounted for and is thus conserved. The equation also suggests that more work is gained by taking more energy at a higher temperature and giving up less energy at a lower temperature. If no energy is given up at the lower temperature ($Q_c = 0$), then it seems that work could be obtained from energy transferred as heat from any body, such as the air around the engine. Such an engine would be able to do more work on hot days than on cold days, but it would always do work as long as the engine's temperature was less than the temperature of the surrounding air.

extension

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A heat engine cannot transfer all energy as heat to do work

Unfortunately, it is impossible to make such an engine. As we have seen, a heat engine carries some substance through a cyclic process during which (1) the substance absorbs energy as heat from a high-temperature reservoir, (2) work is done by the engine, and (3) energy is expelled as heat to a lower-temperature reservoir. In practice, all heat engines operating in a cycle must expel some energy to a lower-temperature reservoir. In other words, it is impossible to construct a heat engine that, operating in a cycle, absorbs energy from a hot reservoir and does an equivalent amount of work.

The requirement that a heat engine give up some energy at a lower temperature in order to do work does not follow from the first law of thermodynamics. This requirement is the basis of what is called the *second law of thermodynamics.* The second law of thermodynamics can be stated as follows: *No cyclic process that converts heat entirely into work is possible.*

According to the second law of thermodynamics, W can never be equal to Q_h in a cyclic process. In other words, some energy must always be transferred as heat to the system's surroundings ($Q_c > 0$).