Figure 9
If all gas particles moved toward the piston, all of the internal energy could be used to do work. This extremely well ordered situation is highly improbable.

Well ordered; high efficiency and highly improbable distribution of velocities

Highly disordered; average efficiency and highly probable distribution of velocities

Greater disorder means there is less energy to do work

Heat engines are limited in that only some of the energy added as heat can be used to do work. Not all of the gas particles move in an orderly fashion toward the piston and give up all of their energy in collision with the piston, as shown on the left in **Figure 9.** Instead, they move in all available directions, as shown on the right in **Figure 9.** They transfer energy through collisions with the walls of the engine cylinder as well as with each other. Although energy is conserved, not all of it is available to do useful work. The motion of the particles of a system (in this case, the gas in the cylinder) is not well ordered and therefore is less useful for doing work.

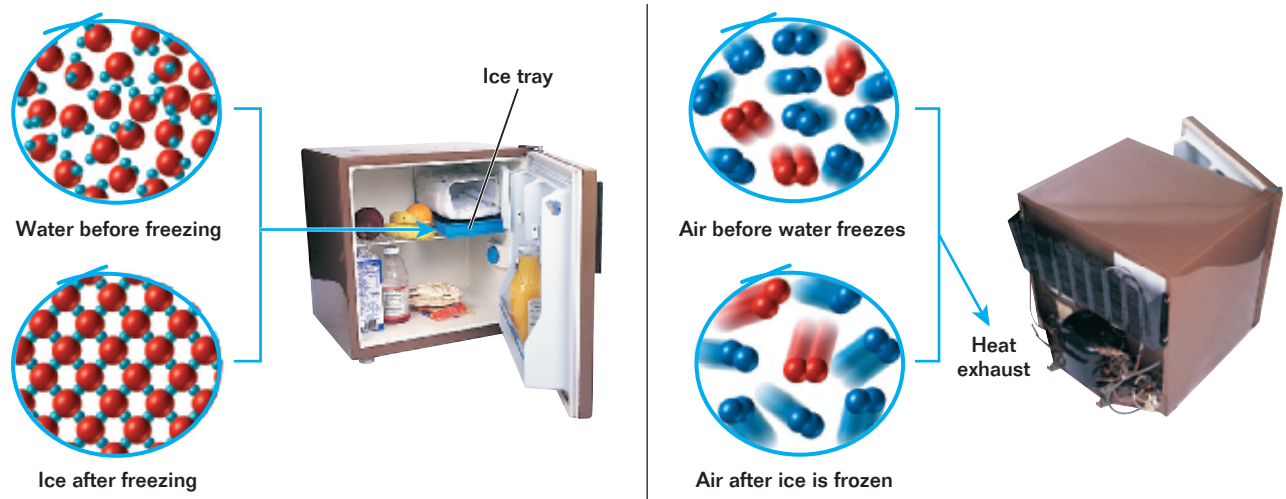
Because of the connection between a system's entropy, its ability to do work, and the direction of energy transfer, the second law of thermodynamics can also be expressed in terms of entropy change. This law applies to the entire universe, not only to a system that interacts with its environment. So, the second law can be stated as follows: *The entropy of the universe increases in all natural processes.*

Note that entropy can decrease for parts of systems, such as the water in the freezer shown in **Figure 10,** provided this decrease is offset by a greater increase in entropy elsewhere in the universe. The water's entropy decreases as it becomes ice, but the entropy of the air in the room is increased by a greater amount as energy is transferred by heat from the refrigerator. The result is that the total entropy of the refrigerator and the room together has increased.

Did you know?

Entropy decreases in many systems on Earth. For example, atoms and molecules become incorporated into complex and orderly biological structures such as cells and tissues. These appear to be spontaneous because we think of the Earth itself as a closed system. So much energy comes from the sun that the disorder in chemical and biological systems is reduced, while the total entropy of the Earth, sun, and intervening space increases.

Figure 10
Because of the refrigerator's less-than-perfect efficiency, the entropy of the outside air molecules increases more than the entropy of the freezing water decreases.



Small decrease in entropy

Large increase in entropy