

## Section Summary

### 15.1 The First Law of Thermodynamics

- The first law of thermodynamics is given as  $\Delta U = Q - W$ , where  $\Delta U$  is the change in internal energy of a system,  $Q$  is the net heat transfer (the sum of all heat transfer into and out of the system), and  $W$  is the net work done (the sum of all work done on or by the system).
- Both  $Q$  and  $W$  are energy in transit; only  $\Delta U$  represents an independent quantity capable of being stored.
- The internal energy  $U$  of a system depends only on the state of the system and not how it reached that state.
- Metabolism of living organisms, and photosynthesis of plants, are specialized types of heat transfer, doing work, and internal energy of systems.

### 15.2 The First Law of Thermodynamics and Some Simple Processes

- One of the important implications of the first law of thermodynamics is that machines can be harnessed to do work that humans previously did by hand or by external energy supplies such as running water or the heat of the Sun. A machine that uses heat transfer to do work is known as a heat engine.
- There are several simple processes, used by heat engines, that flow from the first law of thermodynamics. Among them are the isobaric, isochoric, isothermal and adiabatic processes.
- These processes differ from one another based on how they affect pressure, volume, temperature, and heat transfer.
- If the work done is performed on the outside environment, work ( $W$ ) will be a positive value. If the work done is done to the heat engine system, work ( $W$ ) will be a negative value.
- Some thermodynamic processes, including isothermal and adiabatic processes, are reversible in theory; that is, both the thermodynamic system and the environment can be returned to their initial states. However, because of loss of energy owing to the second law of thermodynamics, complete reversibility does not work in practice.

### 15.3 Introduction to the Second Law of Thermodynamics: Heat Engines and Their Efficiency

- The two expressions of the second law of thermodynamics are: (i) Heat transfer occurs spontaneously from higher- to lower-temperature bodies but never spontaneously in the reverse direction; and (ii) It is impossible in any system for heat transfer from a reservoir to completely convert to work in a cyclical process in which the system returns to its initial state.
- Irreversible processes depend on path and do not return to their original state. Cyclical processes are processes that return to their original state at the end of every cycle.

- In a cyclical process, such as a heat engine, the net work done by the system equals the net heat transfer into the system, or  $W = Q_h - Q_c$ , where  $Q_h$  is the heat transfer from the hot object (hot reservoir), and  $Q_c$  is the heat transfer into the cold object (cold reservoir).
- Efficiency can be expressed as  $\text{Eff} = \frac{W}{Q_h}$ , the ratio of work output divided by the amount of energy input.
- The four-stroke gasoline engine is often explained in terms of the Otto cycle, which is a repeating sequence of processes that convert heat into work.

#### 15.4 Carnot's Perfect Heat Engine: The Second Law of Thermodynamics Restated

- The Carnot cycle is a theoretical cycle that is the most efficient cyclical process possible. Any engine using the Carnot cycle, which uses only reversible processes (adiabatic and isothermal), is known as a Carnot engine.
- Any engine that uses the Carnot cycle enjoys the maximum theoretical efficiency.
- While Carnot engines are ideal engines, in reality, no engine achieves Carnot's theoretical maximum efficiency, since dissipative processes, such as friction, play a role. Carnot cycles without heat loss may be possible at absolute zero, but this has never been seen in nature.

#### 15.5 Applications of Thermodynamics: Heat Pumps and Refrigerators

- An artifact of the second law of thermodynamics is the ability to heat an interior space using a heat pump. Heat pumps compress cold ambient air and, in so doing, heat it to room temperature without violation of conservation principles.
- To calculate the heat pump's coefficient of performance, use the equation  $\text{COP}_{\text{hp}} = \frac{Q_h}{W}$ .
- A refrigerator is a heat pump; it takes warm ambient air and expands it to chill it.

#### 15.6 Entropy and the Second Law of Thermodynamics: Disorder and the Unavailability of Energy

- Entropy is the loss of energy available to do work.
- Another form of the second law of thermodynamics states that the total entropy of a system either increases or remains constant; it never decreases.
- Entropy is zero in a reversible process; it increases in an irreversible process.
- The ultimate fate of the universe is likely to be thermodynamic equilibrium, where the universal temperature is constant and no energy is available to do work.

- Entropy is also associated with the tendency toward disorder in a closed system.

### **15.7 Statistical Interpretation of Entropy and the Second Law of Thermodynamics: The Underlying Explanation**

- Disorder is far more likely than order, which can be seen statistically.
- The entropy of a system in a given state (a macrostate) can be written as
- $S = k \ln W$ ,

where  $k = 1.38 \times 10^{-23}$  J/K is Boltzmann's constant, and  $\ln W$  is the natural logarithm of the number of microstates  $W$  corresponding to the given macrostate.