

Chapter Summary

Essential Idea: Heat can be used to do work.

In this chapter we looked at the connection between heat, work, and the change in internal energy, and we saw how the laws of thermodynamics can be applied to understand the basic operation of practical devices such as engines, refrigerators, and air conditioners.

The First Law of Thermodynamics

The first law of thermodynamics is a statement of energy conservation as it relates to a thermodynamic system. Heat, Q , can be transformed into (or come from) some combination of a change in internal energy, ΔE_{int} , of the system and the work, W , done by the system.

$$Q = \Delta E_{\text{int}} + W \quad . \quad (\text{Equation 15.1: The First Law of Thermodynamics})$$

Q is positive when heat is added to a system, and negative when heat is removed.

ΔE_{int} is positive when the temperature of a system increases, and negative when it decreases.

W is positive when a system expands and does work, and negative when the system is compressed.

Work, and Change in Internal Energy

The work done by a system during a thermodynamic process is equal to the area under the curve corresponding to that process on a P-V diagram.

Change in internal energy: If the temperature of an ideal gas changes the change in internal energy of the gas is proportional to the change in temperature.

$$\Delta E_{\text{int}} = n C_V \Delta T \quad . \quad (\text{Equation 15.4: Change in internal energy})$$

Heat Capacity

C_V is known as the heat capacity at constant volume.

$$\text{Monatomic: } C_V = \frac{3}{2}R \quad \quad \text{Diatomic: } C_V = \frac{5}{2}R \quad \quad \text{Polyatomic: } C_V = 3R$$

$C_p = R + C_V$ is the heat capacity at constant pressure.

$$\text{Monatomic: } C_p = \frac{5}{2}R \quad \quad \text{Diatomic: } C_p = \frac{7}{2}R \quad \quad \text{Polyatomic: } C_p = 4R$$

Special Thermodynamic Processes (see also Figure 15.14 in Section 15-5)

1. **An isochoric (constant volume) process.** There is no work done by the gas: $W = 0$. The heat added to the gas is equal to the change in internal energy: $Q = \Delta E_{\text{int}} = n C_V \Delta T$.
2. **An isobaric (constant pressure) process.** The work done by the gas is $W = P\Delta V$.
3. **An isothermal (constant temperature) process.** There is no change in internal energy, $\Delta E_{\text{int}} = 0$, so $Q = W$. The work done by the gas is given by:

$$Q = W = nRT \ln\left(\frac{V_f}{V_i}\right) \quad (\text{Eq. 15.8: Heat and work for an isothermal process})$$

4. **An adiabatic process.** Such a process is characterized by no heat transfer: $Q = 0$. On the P-V diagram an adiabatic process moves along a line given by:
 $PV^\gamma = \text{constant}$ (Eq. 15.9: **Equation for an adiabatic process on the P-V diagram**)

$$\gamma = \frac{C_P}{C_V} \quad (\text{Equation 15.10: The constant } \gamma \text{ for an adiabatic process})$$

Another useful equation in an adiabatic situation is: $T_f V_f^{\gamma-1} = T_i V_i^{\gamma-1}$. (Eq. 15.11)

Tools for Solving Thermodynamics Problems

- The P-V diagram can help us to visualize what is going on. In addition, the work done by a gas in a process is the area under the curve defining that process on the P-V diagram.
- The ideal gas law, $PV = nRT$, and the first law of thermodynamics, $Q = \Delta E_{\text{int}} + W$.
- The general expression for the change in internal energy, $\Delta E_{\text{int}} = nC_V \Delta T$.
- In specific special cases (see Figure 15.14, and the preceding section in this summary), there are additional relationships that can be used to relate the different parameters.

A Thermodynamic Cycle

A cycle is a sequence of processes that returns a system to its original state. The cycle as a whole satisfies the first law of thermodynamics, as does each of its processes. The change in internal energy for any cycle is always zero, because the system returns to its initial state, and the area of the enclosed region on the P-V diagram is the net work done in the cycle.

Entropy and the Second Law of Thermodynamics

Entropy is in some sense a measure of disorder. The symbol for entropy is S , and the units are J/K. Entropy is sometimes called time's arrow, since entropy tends to increase with time.

$$\Delta S \approx \frac{Q}{T_{\text{av}}}, \quad (\text{Equation 15.13: Approximate change in entropy})$$

where T_{av} is the average temperature of the system while the heat is being transferred.

$$\Delta S \geq 0. \quad (\text{Equation 15.14: The Second Law of Thermodynamics})$$

The entropy of a closed system tends to increase as time goes by.

Heat Engines

A heat engine, such as a car engine, uses a thermodynamic cycle to do work. Cooling devices such as refrigerators and air conditioners are heat engines run in reverse, having work done on them to pump heat from a cooler place to a warmer place.

$$Q_H - Q_L = W. \quad (\text{Eq. 15.15: Energy equation for a heat engine or cooling device})$$

$$e = \frac{W}{Q_H} = \frac{Q_H - Q_L}{Q_H} = 1 - \frac{Q_L}{Q_H}. \quad (\text{Equation 15.16: Efficiency for a heat engine})$$

$$\frac{T_L}{T_H} = \frac{Q_L}{Q_H}. \quad (\text{Equation 15.17: The Carnot relationship for an ideal engine})$$

$$e_{\text{ideal}} = 1 - \frac{T_L}{T_H}. \quad (\text{Equation 15.18: Efficiency for an ideal engine})$$