14.21: The Second Law of Thermodynamics (Summary)

Key Terms

Carnot cycle	cycle that consists of two isotherms at the temperatures of two reservoirs and two adiabatic processes connecting the isotherms
Carnot engine	Carnot heat engine, refrigerator, or heat pump that operates on a Carnot cycle
Carnot principle	principle governing the efficiency or performance of a heat device operating on a Carnot cycle: any reversible heat device working between two reservoirs must have the same efficiency or performance coefficient, greater than that of an irreversible heat device operating between the same two reservoirs
Clausius statement of the second law of thermodynamics	heat never flows spontaneously from a colder object to a hotter object
coefficient of performance	measure of effectiveness of a refrigerator or heat pump
cold reservoir	sink of heat used by a heat engine
disorder	measure of order in a system; the greater the disorder is, the higher the entropy
efficiency (e)	output work from the engine over the input heat to the engine from the hot reservoir
entropy	state function of the system that changes when heat is transferred between the system and the environment
entropy statement of the second law of thermodynamics	entropy of a closed system or the entire universe never decreases
heat engine	device that converts heat into work
heat pump	device that delivers heat to a hot reservoir
hot reservoir	source of heat used by a heat engine
irreversibility	phenomenon associated with a natural process
irreversible process	process in which neither the system nor its environment can be restored to their original states at the same time
isentropic	reversible adiabatic process where the process is frictionless and no heat is transferred
Kelvin statement of the second law of thermodynamics	it is impossible to convert the heat from a single source into work without any other effect
perfect engine	engine that can convert heat into work with 100%100% efficiency
perfect refrigerator (heat pump)	refrigerator (heat pump) that can remove (dump) heat without any input of work
refrigerator	device that removes heat from a cold reservoir
reversible process	process in which both the system and the external environment theoretically can be returned to their original states
third law of thermodynamics	absolute zero temperature cannot be reached through any finite number of cooling steps

Key Equations

Result of energy conservation	$W = Q_h - Q_c$
Efficiency of a heat engine	$e = \frac{W}{Q_h} = 1 - \frac{Q_c}{Q_h}$
Coefficient of performance of a refrigerator	$K_R = \frac{Q_c}{W} = \frac{Q_c}{Q_h - Q}$
Coefficient of performance of a heat pump	$K_P = \frac{Q_h}{W} = \frac{Q_h}{Q_h - Q_c}$
Resulting efficiency of a Carnot cycle	$e = 1 - \frac{T_c}{T_h}$
Performance coefficient of a reversible refrigerator	$K_R = \frac{T_c}{T_h - T_c}$
Performance coefficient of a reversible heat pump	$K_P = \frac{T_h}{T_h - T_c}$
Entropy of a system undergoing a reversible process at a constant temperature	$\Delta S = \frac{Q}{T}$
Change of entropy of a system under a reversible process	$\Delta S = S_B - S_A = \int_A^B dQ/T$
Entropy of a system undergoing any complete reversible cyclic process	$\oint dS = \oint \frac{dQ}{T} = 0$
Change of entropy of a closed system under an irreversible process	$\Delta S \geq 0$
Change in entropy of the system along an isotherm	$\lim_{T \to 0} (\Delta S)_T = 0$

Summary

4.2 Reversible and Irreversible Processes

- A reversible process is one in which both the system and its environment can return to exactly the states they were in by following the reverse path.
- An irreversible process is one in which the system and its environment cannot return together to exactly the states that they were in.
- The irreversibility of any natural process results from the second law of thermodynamics.

4.3 Heat Engines

- The work done by a heat engine is the difference between the heat absorbed from the hot reservoir and the heat discharged to the cold reservoir, that is, $W = Q_h - Q_c$.
- The ratio of the work done by the engine and the heat absorbed from the hot reservoir provides the efficiency of the engine, that is, $e = W/Q_h = 1 - Q_c/Q_h$.

4.4 Refrigerators and Heat Pumps

- A refrigerator or a heat pump is a heat engine run in reverse.
- The focus of a refrigerator is on removing heat from the cold reservoir with a coefficient of performance K_R.
- The focus of a heat pump is on dumping heat to the hot reservoir with a coefficient of performance K_P.

4.5 Statements of the Second Law of Thermodynamics

- The Kelvin statement of the second law of thermodynamics: It is impossible to convert the heat from a single source into work without any other effect.
- The Kelvin statement and Clausius statement of the second law of thermodynamics are equivalent.

4.6 The Carnot Cycle

- The Carnot cycle is the most efficient engine for a reversible cycle designed between two reservoirs.
- The Carnot principle is another way of stating the second law of thermodynamics.

4.7 Entropy

- The change in entropy for a reversible process at constant temperature is equal to the heat divided by the temperature. The entropy change of a system under a reversible process is given by $\Delta S = \int_A^B dQ/T$.
- A system's change in entropy between two states is independent of the reversible thermodynamic path taken by the system when it makes a transition between the states.

4.8 Entropy on a Microscopic Scale

- Entropy can be related to how disordered a system is—the more it is disordered, the higher is its entropy. In any irreversible process, the universe becomes more disordered.
- According to the third law of thermodynamics, absolute zero temperature is unreachable.
