1.8: Temperature and Heat (Summary)

Key Terms

absolute temperature scale	scale, such as Kelvin, with a zero point that is absolute zero
absolute zero	temperature at which the average kinetic energy of molecules is zero
calorie (cal)	energy needed to change the temperature of 1.00 g of water by **1.00°C**
calorimeter	container that prevents heat transfer in or out
calorimetry	study of heat transfer inside a container impervious to heat
Celsius scale	temperature scale in which the freezing point of water is **0°C** and the boiling point of water is **100°C**
coefficient of linear expansion	(α) material property that gives the change in length, per unit length, per $1-{}^{\circ}C$ change in temperature; a constant used in the calculation of linear expansion; the coefficient of linear expansion depends to some degree on the temperature of the material
coefficient of volume expansion	(β) similar to αα but gives the change in volume, per unit volume, per $1-{}^{\circ}C$ change in temperature
conduction	heat transfer through stationary matter by physical contact
convection	heat transfer by the macroscopic movement of fluid
critical point	for a given substance, the combination of temperature and pressure above which the liquid and gas phases are indistinguishable
critical pressure	pressure at the critical point
critical temperature	temperature at the critical point
degree Celsius	(**°C**) unit on the Celsius temperature scale
degree Fahrenheit	(**°F**) unit on the Fahrenheit temperature scale
emissivity	measure of how well an object radiates
Fahrenheit scale	temperature scale in which the freezing point of water is **32°F** and the boiling point of water is **212°F**
greenhouse effect	warming of the earth that is due to gases such as carbon dioxide and methane that absorb infrared radiation from Earth's surface and reradiate it in all directions, thus sending some of it back toward Earth
heat	energy transferred solely due to a temperature difference
heat of fusion	energy per unit mass required to change a substance from the solid phase to the liquid phase, or released when the substance changes from liquid to solid
heat of sublimation	energy per unit mass required to change a substance from the solid phase to the vapor phase
heat of vaporization	energy per unit mass required to change a substance from the liquid phase to the vapor phase

heat transfer	movement of energy from one place or material to another as a result of a difference in temperature
Kelvin scale (K)	temperature scale in which 0 K is the lowest possible temperature, representing absolute zero
kilocalorie (kcal)	energy needed to change the temperature of 1.00 kg of water between **14.5°C** and **15.5°C**
latent heat coefficient	general term for the heats of fusion, vaporization, and sublimation
mechanical equivalent of heat	work needed to produce the same effects as heat transfer
net rate of heat transfer by radiation	$P_{net} = \sigma eA(T_2^4 - T_1^4)$
phase diagram	graph of pressure vs. temperature of a particular substance, showing at which pressures and temperatures the phases of the substance occur
radiation	energy transferred by electromagnetic waves directly as a result of a temperature difference
rate of conductive heat transfer	rate of heat transfer from one material to another
specific heat	amount of heat necessary to change the temperature of 1.00 kg of a substance by **1.00°C**; also called "specific heat capacity"
Stefan-Boltzmann law of radiation	$P = \sigma AeT^4$, where $\sigma = 5.67 \times 10^{-8} J/s \cdot m^2 \cdot K^4$ is the Stefan-Boltzmann constant, **A** is the surface area of the object, **T** is the absolute temperature, and **e** is the emissivity
sublimation	phase change from solid to gas
temperature	quantity measured by a thermometer, which reflects the mechanical energy of molecules in a system
thermal conductivity	property of a material describing its ability to conduct heat
thermal equilibrium	condition in which heat no longer flows between two objects that are in contact; the two objects have the same temperature
thermal expansion	change in size or volume of an object with change in temperature
thermal stress	stress caused by thermal expansion or contraction
triple point	pressure and temperature at which a substance exists in equilibrium as a solid, liquid, and gas
vapor	gas at a temperature below the boiling temperature
vapor pressure	pressure at which a gas coexists with its solid or liquid phase
zeroth law of thermodynamics	law that states that if two objects are in thermal equilibrium, and a third object is in thermal equilibrium with one of those objects, it is also in thermal equilibrium with the other object

Key Equations

Linear thermal expansion	$\Delta L = \alpha L \Delta T$
Thermal expansion in two dimensions	$\Delta A = 2\alpha A \Delta T$
Thermal expansion in three dimensions	$\Delta V = \beta V \Delta T$
Heat transfer	$Q = mc\Delta T$

Transfer of heat in a calorimeter	$Q_{cold} + Q_{hot} = 0$
Heat due to phase change (melting and freezing)	$Q = mL_f$
Heat due to phase change (evaporation and condensation)	$Q = mLv$
Rate of conductive heat transfer	$P = \frac{kA(T_h - T_c)}{d}$
Net rate of heat transfer by radiation	$P_{net} = \sigma e A(T_2^4 - T_1^4)$

Summary

1.2 Temperature and Thermal Equilibrium

- Temperature is operationally defined as the quantity measured by a thermometer. It is proportional to the average kinetic energy of atoms and molecules in a system.
- Thermal equilibrium occurs when two bodies are in contact with each other and can freely exchange energy. Systems are in thermal equilibrium when they have the same temperature.
- The zeroth law of thermodynamics states that when two systems, **A** and **B**, are in thermal equilibrium with each other, and B is in thermal equilibrium with a third system **C**, then **A** is also in thermal equilibrium with **C**.

1.3 Thermometers and Temperature Scales

- Three types of thermometers are alcohol, liquid crystal, and infrared radiation (pyrometer).
- The three main temperature scales are Celsius, Fahrenheit, and Kelvin. Temperatures can be converted from one scale to another using temperature conversion equations.
- The three phases of water (ice, liquid water, and water vapor) can coexist at a single pressure and temperature known as the triple point.

1.4 Thermal Expansion

- Thermal expansion is the increase of the size (length, area, or volume) of a body due to a change in temperature, usually a rise. Thermal contraction is the decrease in size due to a change in temperature, usually a fall in temperature.
- Thermal stress is created when thermal expansion or contraction is constrained.

1.5 Heat Transfer, Specific Heat, and Calorimetry

- Heat and work are the two distinct methods of energy transfer.
- Heat transfer to an object when its temperature changes is often approximated well by $Q = mc\Delta T$,,where m is the object’s mass and cis the specific heat of the substance.

1.6 Phase Changes

- Most substances have three distinct phases (under ordinary conditions on Earth), and they depend on temperature and pressure.
- Two phases coexist (i.e., they are in thermal equilibrium) at a set of pressures and temperatures.
- Phase changes occur at fixed temperatures for a given substance at a given pressure, and these temperatures are called boiling, freezing (or melting), and sublimation points.

1.7 Mechanisms of Heat Transfer

- Heat is transferred by three different methods: conduction, convection, and radiation.
- Heat conduction is the transfer of heat between two objects in direct contact with each other.
- The rate of heat transfer P (energy per unit time) is proportional to the temperature difference $T_h - T_c$ and the contact area A and inversely proportional to the distance d between the objects.
- Convection is heat transfer by the macroscopic movement of mass. Convection can be natural or forced, and generally transfers thermal energy faster than conduction. Convection that occurs along with a phase change can transfer energy from cold regions to warm ones.
- Radiation is heat transfer through the emission or absorption of electromagnetic waves.
- The rate of radiative heat transfer is proportional to the emissivity e. For a perfect blackbody, $e = 1$, whereas a perfectly white, clear, or reflective body has $e = 0$, with real objects having values of e between 1 and 0.
- The rate of heat transfer depends on the surface area and the fourth power of the absolute temperature:

$$P=\sigma eAT^4,$$

where $\sigma=5.67\times10^{-8}J/s\cdot m^2\cdot K^4$ is the Stefan-Boltzmann constant and **e** is the emissivity of the body. The net rate of heat transfer from an object by radiation is

$$\frac{Q_{net}}{t}=\sigma eA(T_2^4-T_1^4)\ ,$$

where T_1 is the temperature of the object surrounded by an environment with uniform temperature T_2 and **e** is the emissivity of the object.