Lecture 9

Temperature and Heat

Heat transfer

movement of energy from one place or material to another as a result of a difference in temperature.

No Temperature Difference → No Heat flow

Temperature

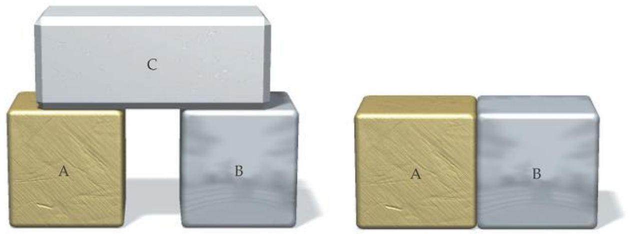
quantity measured by a thermometer, which reflects the mechanical energy of molecules in a system.

Thermal equilibrium

condition in which heat no longer flows between two objects that are in contact; the two objects have the same temperature.

The Zeroth Law of Thermodynamics

If two objects are each in thermal equilibrium with a third object, then the two objects are in thermal equilibrium with each other.



Thermodynamics

Thermodynamics is the scientific study of work, heat, and the related properties of chemical and mechanical systems.

Thermometers and Temperature Scales

Temperature Measurement

Requirement:

A substance that exhibits a measureable change in one of its physical properties as the temperature changes.

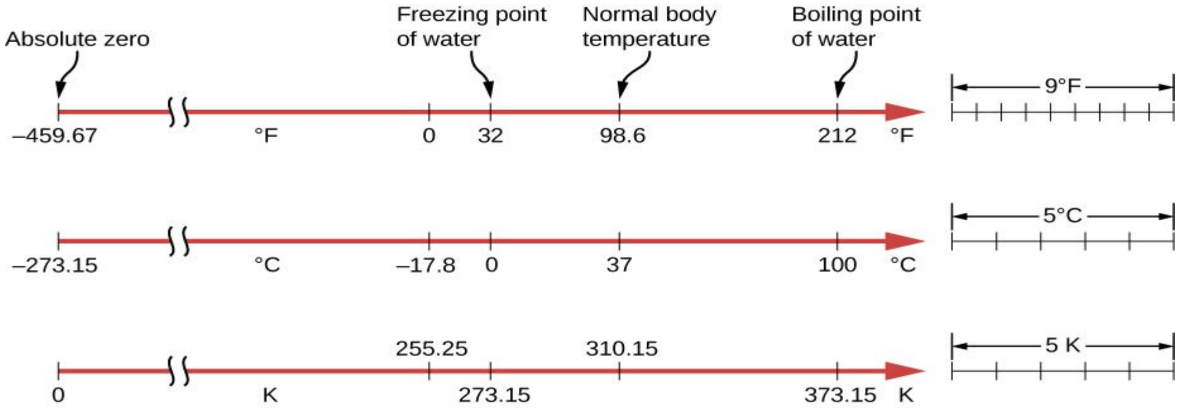
Examples:

Volume change with temperature is a common physical property used for the measurement of temperature

The change of electrical resistance with temperature is also used to measure temperature.

- 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.

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
Celsius scale
temperature scale in which the freezing point of water is 0 ºC and the boiling point of water is 100 ºC
degree Celsius
(C) unit on the Celsius temperature scale
degree Fahrenheit
(F) unit on the Fahrenheit temperature scale
Fahrenheit scale
temperature scale in which the freezing point of water is 32 F and the boiling point of water is 212 F
Kelvin scale (K)
temperature scale in which 0 K is the lowest possible temperature, representing absolute zero
triple point
pressure and temperature at which a substance exists in equilibrium as a solid, liquid, and gas
Relationships between the Fahrenheit, Celsius, and Kelvin temperature scales are shown. The relative sizes of the scales are also shown.



To convert from…	**Use this equation…**
Celsius to Fahrenheit	$T_F = \frac{9}{5}T_C + 32$
Fahrenheit to Celsius	$T_C = \frac{5}{9}T_F - 32$
Celsius to Kelvin	$T_K = T_C + 273.15$
Kelvin to Celsius	$T_C = T_K - 273.15$
Fahrenheit to Kelvin	$T_K = \frac{5}{9}(T_F - 32) + 273.15$
Kelvin to Fahrenheit	$T_F = \frac{9}{5}(T_K - 273.15) + 32$

An Ideal Gas

- The ideal gas law relates the pressure and volume of a gas to the number of gas molecules and the temperature of the gas.
- A mole of any substance has a number of molecules equal to the number of atoms in a 12-g sample of carbon-12. The number of molecules in a mole is called Avogadro's number N_A, $\mathbf{N_A = 6.022 \times 10^{23}\ mol^{-1}}$
  The number of moles can be determined from the mass of the substance
  $$n = \frac{m}{M}$$
- **M** is the molar mass of the substance.
- Can be obtained from the periodic table
- Is the atomic mass expressed in grams/mole
  Example: He has mass of **4.00 u so M = 4.00 g/ mol**
- ***m*** is the mass of the sample.
- ***n*** is the number of moles.

Gas Laws

When a gas is kept at a constant temperature, its pressure is inversely proportional to its volume (Boyle's law).

When a gas is kept at a constant pressure, its volume is directly proportional to its temperature (Charles and Gay-Lussac's law).

When the volume of the gas is kept constant, the pressure is directly proportional to the temperature (Guy-Lussac'slaw).

Ideal Gas Law

The equation of state for an ideal gas combines and summarizes the other gas laws:

$PV = nRT$ This is known as the ideal gas law.

R is a constant, called the Universal Gas Constant.

R= 8.314 J/mol.K = 0.08214 L.atm/mol·K

From this, you can determine that 1 mole of any gas at atmospheric pressure and at 0^oC is 22.4 L.

It is common to call P, V, and T the thermodynamic variables of an ideal gas.

Internal Energy

Internal energy is all the energy of a system that is associated with its microscopic components.

- These components are its atoms and molecules.
- The system is viewed from a reference frame at rest with respect to the center of mass of the system.

The kinetic energy due to its motion through space is not included.

Internal energy does include kinetic energies due to:

- **Random translational motion**
- **Rotational motion**
- **Vibrational motion**

Internal energy also includes potential energy between molecules

Heat

Heat is defined as the transfer of energy across the boundary of a system due to a temperature difference between the system and its surroundings.

The term heat will also be used to represent the amount of energy transferred by this method.

There are many common phrases that use the word "heat" incorrectly.

Heat, internal energy, and temperature are all different quantities.

- Be sure to use the correct definition of heat.
- **One calorie** is the amount of energy transfer necessary to raise the temperature of 1 g of water from **14.5ºC to 15.5ºC**.
- The "Calorie" used for food is actually 1 kilocalorie.
- The standard in the text is to use Joules.

more precise, measurements determined the amount of mechanical energy needed to raise the temperature of water from **14.5ºC to 15.5ºC**.

1 cal= 4.186 J

- This is known as the **mechanical equivalent of heat.**

Heat Capacity

The **heat capacity**, **C**, of a particular sample is defined as the amount of energy needed to raise the temperature of that sample by **1ºC**.

If energy Q produces a change of temperature of ΔT, then $Q = C\Delta T$.

Specific Heat

Specific heat, **c**, is the heat capacity per unit mass.

If energy Q transfers to a sample of a substance of mass m and the temperature changes by ΔT, then the specific heat is

$$c = \frac{Q}{m\Delta T}$$

The specific heat is essentially a measure of how thermally insensitive a substance is to the addition of energy.

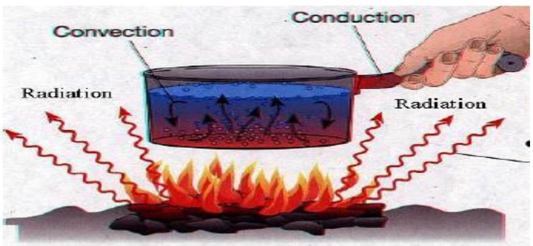
- The greater the substance's specific heat, the more energy that must be added to a given mass to cause a particular temperature change.

The equation is often written in terms of **Q** : $Q = m\, c\, \Delta T$

Water has the highest specific heat of common materials.

Mechanisms of Energy Transfer In Thermal Processes

The heat is a transfer of the energy from a high temperature object to a lower temperature one. There are various mechanisms responsible for the transfer: Conduction, Convection, Radiation



Conduction

It is an exchange of kinetic energy between microscopic particles by collisions.

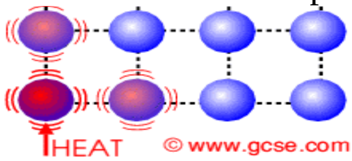
- The microscopic particles can be atoms, molecules or free electrons.
- Less energetic particles gain energy during collisions with more energetic particles.

Rate of conduction depends upon the characteristics of the substance.

In general, metals are good thermal conductors.

- They contain large numbers of electrons that are relatively free to move through the metal.
- They can transport energy from one region to another.

Poor conductors include asbestos, paper, and gases. Conduction can occur only if there is a difference in temperature between two conducting medium.

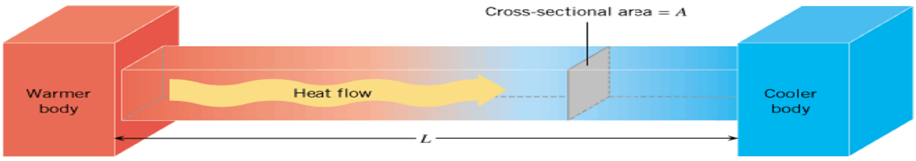


Conduction, equation

The slab at right allows energy to transfer from the region of higher temperature to the region of lower temperature.

The rate of transfer is given by:

$$H = \frac{Q}{t} = kA\left(\frac{\Delta T}{L}\right)$$



A is the cross-sectional area. L is the length of a rod

H (or **P**) = rate of conduction heat transfer (Watt)

k is the thermal conductivity of the material.

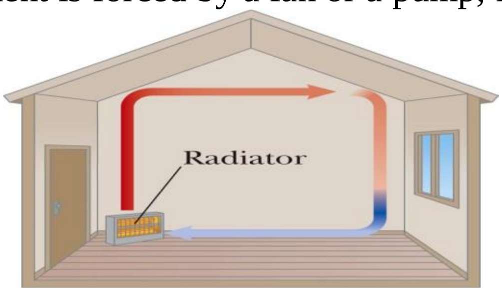
- Good conductors have high ***k*** values and good insulators have low ***k*** values

Convection

Energy transferred by the movement of a substance.

It is a form of matter transfer:

- When the movement results from differences in density, it is called *natural convection.*
- When the movement is forced by a fan or a pump, it is called *forced convection.*



Radiation

Radiation does not require physical contact.

All objects radiate energy continuously in the form of electromagnetic waves due to thermal vibrations of their molecules.

Rate of radiation is given by **Stefan's law.**

- **$P = \sigma A e T^4$**
- **P** is the rate of energy transfer, in Watts.
- **$\sigma = 5.6696 \times 10^{-8} W/m^2 .K^4$**
- **A** is the surface area of the object.

e is a constant called the emissivity.

e varies from **0** to **1**

- The emissivity is also equal to the absorptivity.
- T is the temperature in Kelvins.

An ***ideal absorber*** is defined as an object that absorbs all of the energy incident on it.

***e* = 1**

This type of object is called a **black body.**

Energy Absorption and Emission by Radiation

With its surroundings, the rate at which the object at temperature T with surroundings at T_o radiates is

$$P_{net} = \sigma A e \left(T^4 - T_o^4\right)$$

- When an object is in equilibrium with its surroundings, it radiates and absorbs at the same rate.
- Its temperature will not change

Example:1

Pure helium gas is admitted into a tank containing a movable piston. The initial volume, pressure and temperature of the gas are $15\times10^{-3}m^3$, 200kPa and 300K respectively. If the volume is decreased to $12\times10^{-3}m^3$and the pressure is increased to 350KPa, find the final temperature of the gas.

Solution

Since the gas cannot escape from the tank then the number of moles is constant,

$$\frac{p_1 V_1}{T_1} = \frac{p_2 V_2}{T_2}$$

$$T_2 = \left(\frac{p_2 V_2}{p_1 V_1}\right) T_1 = \frac{3.5\ atm\ .12\ liters}{2\ atm\ .15\ liters}(300K) = 420\ K$$

Example:2

A quantity of hot water at 91°C and another cold one at 12°C. How much kilogram of each one is needed to make an 800 liter of water bath at temperature of 35°C.

Solution

Assume the mass of hot water $m_H$and cold one is m_C,

800 liter of water is equivalent to 800 kg, *So* $m_H + m_C = 800$,

From the conservation of energy

$$m_H C_w (T_H - T_f) = m_C C_w (T_f - T_C)$$

$$T_H = 92°C,\ \ T_C = 12°C,\ \ T_f = 35°C.$$

$$56\, m_H = 23\, m_C,$$

- so

$$m_C = 2.43\, m_H$$

- So by substitution

$$3.43\, m_H = 800,$$

$$m_H = 233\ kg,\ \text{and}\ m_C = 567\ kg$$

Example:3

An aluminum pot contains water that is kept steadily boiling (100 ºC).The bottom surface of the pot, which is 12 mm thick and $1.5\text{x}10^4$ mm^2 in area, is maintained at a temperature of 102°C by an electric heating unit. Find the rate at which heat is transferred through the bottom surface. Compare this with a copper based pot.

Solution

$$H = kA\left(\frac{\Delta T}{L}\right)$$

- For the aluminum base: $T_H = 102\ °C, T_C = 100\ °C,\ L = 12\ mm = 0.012\ m,\ K_{Al} = 238\ Wm^{-1}K^{-1}$, Base area $A = 1.5\text{x}10^4\ mm^2 = 0.015\ m^2$.

$$H_{Al} = 238\ (0.015)\ \frac{(102 - 100)}{0.012} = 588W$$

- For the copper base $K_{Cu} = 397\ Wm^{-1}K^{-1}$.

$$H_{Cu} = 397\ (0.015)\ \frac{(102 - 100)}{0.012} = 1003W$$

Example:4

Air directly above the radiator is warmed and expands. The density of the air decreases, and it rises. A continuous air current is established

Example:5

A student tries to decide what to wear is staying in a room that is at 20°C. If the skin temperature is 37°C, how much heat is lost from the body in 10 minutes? Assume that the emissivity of the body is 0.9 and the surface area of the student is 1.5 m^2.

Solution

Using the Stefan-Boltzmann's law

$$P_{net} = e\ \sigma\ A\ (T^4 - T_s^4) = (5.67\times10^{-8})(0.9)(1.5)(310^4 - 293^4) = 143\,watt.$$

The total energy lost during 10 min is

$$Q = P_{net}\ \Delta t = 143 \times 600 = 85.8\ kJ$$