College Of Engineering
University Of Anbar

كليـــة الهندسة
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Dept. of Chem. & Petrochemical Engineering
Subject : Physics
First Stage

Physics

Chapter 7– Temperature and Thermodynamics

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Calorimetry

One technique for measuring specific heat involves heating a material, adding it to a sample of water, and recording the final temperature.

This technique is known as **calorimetry.**

- A calorimeter is a device in which this energy transfer takes place.

The system of the sample and the water is isolated.

Conservation of energy requires that the amount of energy that leaves the sample equals the amount of energy that enters the water.

- Conservation of Energy gives a mathematical expression of this:

  $Q_{cold} = -Q_{hot}$

If the temperature increases:

- Q and ΔT are positive
- Energy transfers into the system

If the temperature decreases:

- Q and ΔT are negative
- Energy transfers out of the system

Calorimetry, final

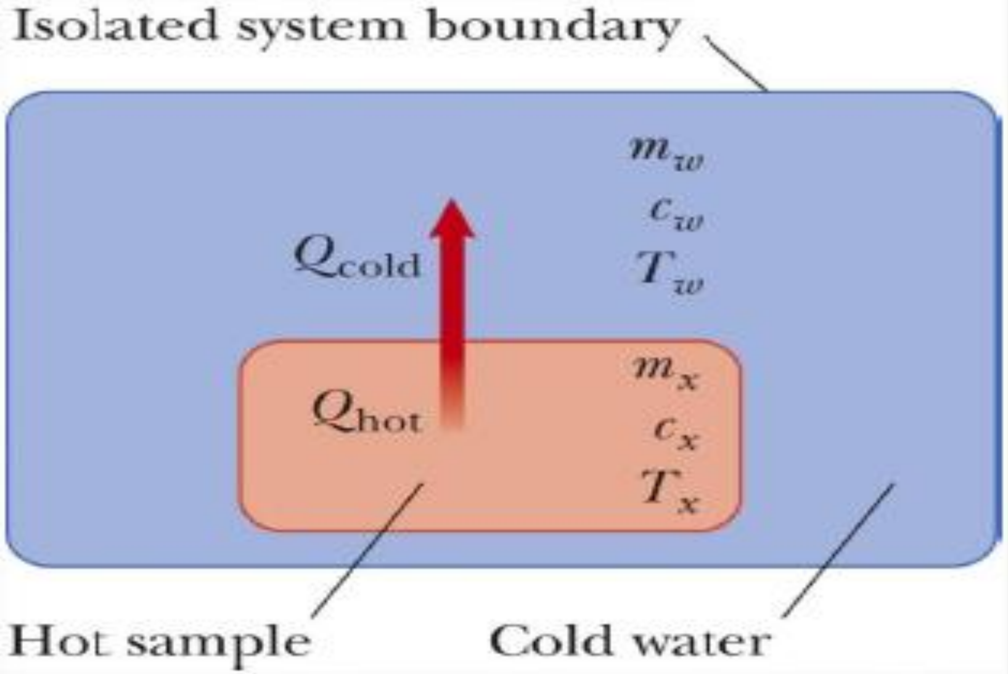
T_f is the final temperature after the system comes to equilibrium.

The subscript *w* represent values for water and *x* represents the values for the sample whose spcific heat is to be determined.

Since each Q = mcΔT, the calorimetry equation can be expressed as

$$m_w c_w (T_f - T_w) = -m_x c_x (T_f - T_x)$$

- Technically, the mass of the container should be included, but if $m_w >> m_{container}$ it can be neglected.



- Example: An ingot of metal is heated and then dropped into a beaker of water. The equilibrium temperature is measured:

$$c_x = \frac{m_w c_w (T_f - T_w)}{m_x (T_x - T_f)}$$

$$= \frac{(0.400\,\text{kg})(4186\,\text{J/kg}\cdot{}^\circ\text{C})(22.4^\circ\text{C} - 20.0^\circ\text{C})}{(0.0500\,\text{kg})(200.0^\circ\text{C} - 22.4^\circ\text{C})}$$

$$= 453\,\text{J/kg}\cdot{}^\circ\text{C}$$

Supercooling

If liquid water is held perfectly still in a very clean container, it is possible for the temperature to drop below 0° C without freezing.

This phenomena is called **supercooling.**

It arises because the water requires a disturbance of some sort for the molecules to move apart and start forming the open ice crystal structures.

- This structure makes the density of ice less than that of water.

If the supercooled water is disturbed, it immediately freezes and the energy released returns the temperature to 0° C.

Superheating

Water can rise to a temperature greater than 100° C without boiling.

This phenomena is called **superheating.**

The formation of a bubble of steam in the water requires nucleation site.

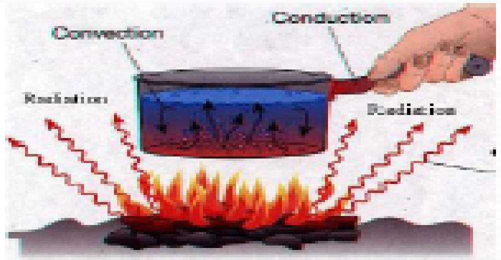
- This could be a scratch in the container or an impurity in the water.

When disturbed, the superheated water can become explosive.

- The bubbles will immediately form and hot water is forced upward and out of the container.

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.

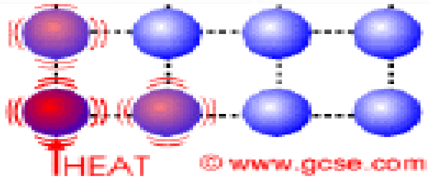
- The microscopic particles can be atoms, molecules or free electrons.

- Less energetic particles gain energy during collisions with more energetic particles.

Rate of conduction depends upon the characteristics of the substance.

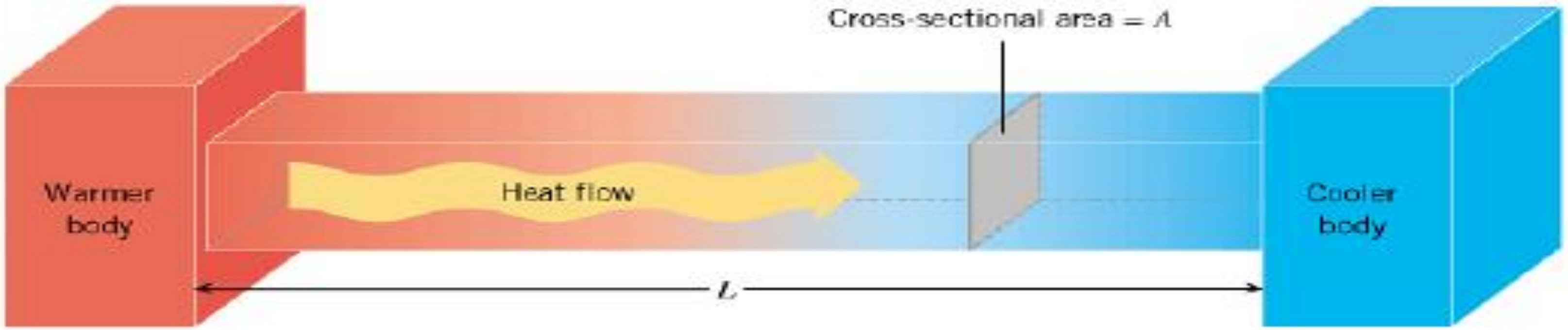
In general, metals are good thermal conductors.

- 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

TABLE 20.3

Thermal Conductivities

Substance	Thermal Conductivity (W/m · °C)
Metals (at 25°C)	
Aluminum	238
Copper	397
Gold	314
Iron	79.5
Lead	34.7
Silver	427
Nonmetals (approximate values)	
Asbestos	0.08
Concrete	0.8
Diamond	2 300
Glass	0.8
Ice	2
Rubber	0.2
Water	0.6
Wood	0.08
Gases (at 20°C)	
Air	0.023 4
Helium	0.138
Hydrogen	0.172
Nitrogen	0.023 4
Oxygen	0.023 8

Example

- An aluminum pot contains water that is kept steadily boiling (100 °C). The bottom surface of the pot, which is 12 mm thick and 1.5×10^4 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 $A = 1.5 \times 10^4\ mm^2 = 0.015\ m^2$.

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

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

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

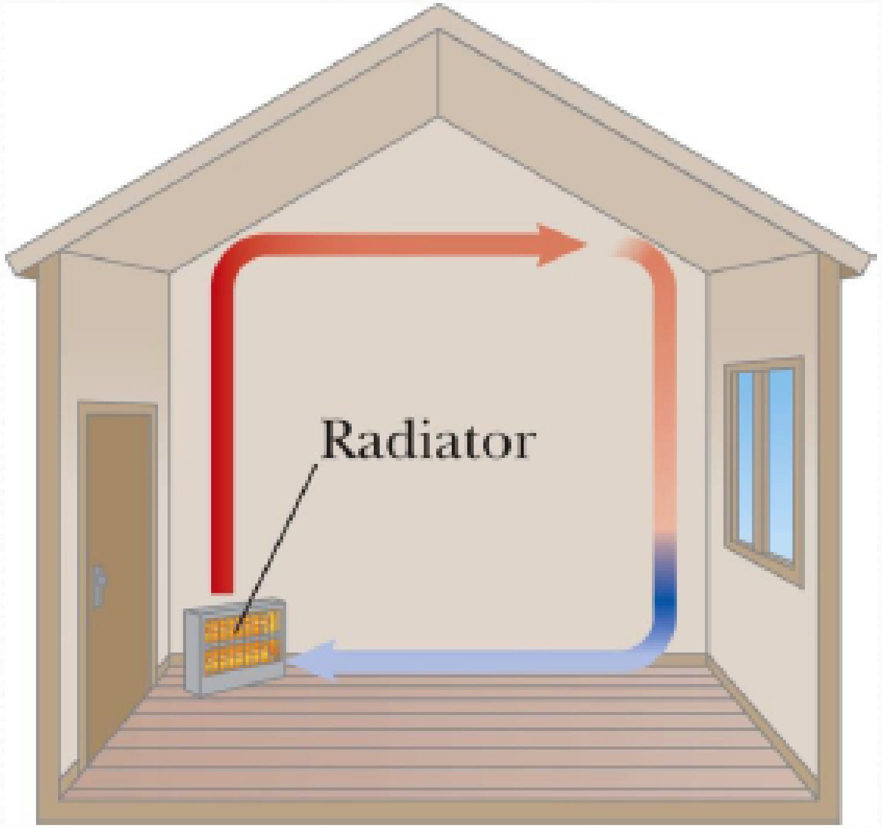
Convection

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.*

Example



Air directly above the radiator is warmed and expands.

The density of the air decreases, and it rises.

A continuous air current is established

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.
- $\sigma = 5.6696 \times 10^{-8}\ W/m^2 \cdot K^4$
- 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

- $P_{net} = \sigma A e \,(T^4 - T_o^4)$
- When an object is in equilibrium with its surroundings, it radiates and absorbs at the same rate.
  - Its temperature will not change

Example: 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 m2.

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

$$Q = P_{net}\,\Delta t = 143\times600 = 85.8\,kJ$$

The Dewar Flask

A Dewar flask is a container designed to minimize the energy losses by conduction, convection, and radiation.

- Invented by Sir James Dewar (1842 – 1923)

It is used to store either cold or hot liquids for long periods of time.

- A Thermos bottle is a common household equivalent of a Dewar flask.

The space between the walls is a vacuum to minimize energy transfer by conduction and convection.

The silvered surface minimizes energy transfers by radiation.

- Silver is a good reflector.

The size of the neck is reduced to further minimize energy losses.