LEcTure 2  THERMAL EXPANSION AND HEAT ABSORPTION

Text Sections 19.5, 19.6, 19.7

Sample Problems 19.3, 19.5, 19.6, 19.7

Suggested Questions 5

Suggested Problems 29P

Summary Thermal expansion
Heat absorbed by solids and liquids
Heat capacity and specific heat
Molar specific heat
Heat of transformation (fusion and vaporisation)

Specific objectives

• Calculate linear, areal and volumetric expansion
• Explain heat in terms of internal energy
• Explain the concept of heat capacity
• Use molar and specific heats in numerical calculations
• Explain the concept of the heat of transformation
• Use heats of transformation in numerical calculations
Thermal expansion

For small changes in temperature $\Delta T \ll T$ (in kelvin) the change in length $\Delta L$ of a solid material is given by:

$$
\Delta L = L \alpha \Delta T
$$

where $\alpha$ is called the coefficient of linear expansion of the material (See Table 19-2). It has units $K^{-1}$.

For example, $\alpha$ for steel is $1.1 \times 10^{-5} \, K^{-1}$.

Note that all pieces of the material (and any holes) will expand by the same proportion (See Fig 19-10).

Bimetallic strips, ie. two flat strips of different metals welded together at one temperature, become curved at other temperatures because the metals have different values for $\alpha$ (See Fig 19-9). They are often used as thermostats.

For small changes in temperature $\Delta T \ll T$ the change in area $\Delta A$ of a solid material is given by:

$$
\Delta A = A 2 \alpha \Delta T
$$

For small changes in temperature $\Delta T \ll T$ the change in volume $\Delta V$ of a solid material or a liquid is given by:

$$
\Delta V = V \beta \Delta T
$$

where $\beta$ is called the coefficient of volume expansion. For a solid $\beta = 3 \alpha$.

$\alpha$ and $\beta$ are slightly temperature dependent but this can usually be neglected.

The temperature dependence is important for water near its freezing point at $0 \, ^\circ C$. $\beta$ for water is negative below $4 \, ^\circ C$ and positive above. The volume of water decreases with temperature below $4 \, ^\circ C$, passes through a minimum and then increases with temperature. The density passes through a maximum at $4 \, ^\circ C$. When water is cooled from above at temperatures below $4 \, ^\circ C$ the colder water is lighter than the warmer water and does not sink. It freezes to form an insulating layer of ice which keeps the water below above freezing point. This is good for fish!
Heat transfer

A flow of energy to or from a system due to a temperature difference between it and its surroundings. It is meaningless to talk about the “amount of heat in a system” since energy can be converted to many other forms. The SI unit of heat transfer is joule abbreviated as J.

An example: A block of ice below freezing point in an insulated box on a hot plate which transfers heat to the contents of the box at a slow constant rate.

Initially the temperature increases at a constant rate until the ice is at 0 °C. The temperature then remains constant until all the ice melts. The temperature then increases at a constant rate until the water is at 100 °C. The temperature then remains constant until all the water has been converted to steam. There are two different types of behaviour to describe.

* * *

Heat capacity, specific heat, molar specific heat

If heat $Q$ is transferred to an object raising its temperature from $T_i$ to $T_f$ then

$$Q = C (T_f - T_i)$$

where $C$ is the heat capacity of the object. The SI unit for $C$ is J . K$^{-1}$.

The heat capacity depends on the amount of material in the object. For objects made of a single substance

$$C = m c$$

where $m$ is the mass of the object and $c$ is the specific heat. Specific heat is a characteristic property of the substance (ie. independent of quantity) and can be found in tables (See Table 19-3). It has SI unit J . kg$^{-1}$ . K$^{-1}$.

Specific heat depends on the conditions, e.g. temperature and pressure, under which heat is transferred. The specific heats for solids and liquids are usually measured at constant pressure and in most cases they change very little with temperature. Specific heats for gases are measured either at constant volume or at constant pressure. These two specific heats differ substantially but again have weak temperature dependences.

Alternatively the molar specific heat of a substance is tabulated. This is the heat capacity $C$ of an object divided by the number of moles of substance $n$ in the object. It has SI unit J . mol$^{-1}$ . K$^{-1}$.
An interesting puzzle: Why are the molar specific heats of most solids at room temperature approximately equal to 25 J . mol$^{-1}$. K$^{-1}$? This gives important information about the microscopic nature of matter! As we shall see later the molar specific heats of gases also have interesting values.

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Heats of transformation

The quantity of heat transferred when mass $m$ of a substance changes from one phase to another is

$$Q = mL$$

$L$ is called the heat of transformation (See Table 19-4). It has SI units J . kg$^{-1}$.

| Solid to liquid: | Heat of fusion $L_F$ |
| Liquid to gas:   | Heat of vaporisation $L_V$ |