6.3. LATENT HEAT

The term *'latent'* means hidden. Latent heat is that heat that does not show its presence in terms of a change in temperature. It is the amount of heat that is absorbed by an object in order to undergo a change of state. Whenever energy is transferred between a substance and its surroundings, the substance undergoes a change in temperature. However, there are situations, commonly known as **phase changes** where the energy transfer in a substance does not result in change in temperature. The two common phase changes are melting and boiling. Consider a block of ice at a temperature of - 10°C under a pressure of one atmosphere. If thermal energy is applied to the ice at a uniform rate, then the temperature of the ice will rise to 0°C. As more energy is supplied, the ice melts but its temperature remains constant. When all the ice has melted, the temperature rises again until boiling begins at 100°C. During boiling the temperature remains constant. When all the water has formed steam the temperature rises above 100°C. These changes are shown in the figure below:

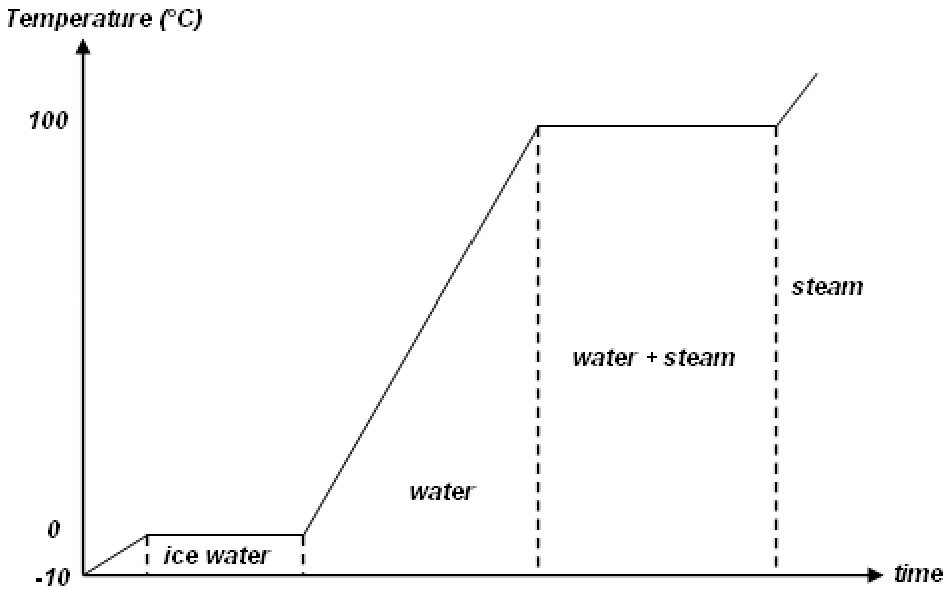

Figure:6.4: Change of state of the matter curve

During the horizontal section of the graph, thermal energy is being transferred without a rise in temperature. I.e. the particles are gaining potential energy rather than kinetic energy.

6.3.1. LATENT HEAT OF FUSION

The latent heat of fusion of a substance is the amount of heat the substance requires (absorbs) to change its state from solid to liquid at a constant temperature.

The specific latent heat of fusion of a substance is the amount of heat energy required to change unit mass (1kg) of the substance from solid to liquid without change of temperature. The symbol for specific latent heat of fusion is L_f and it SI unit is **joule per kilogram (J/kg)**.

$$Specific\ latent\ heat = \frac{heat\ energy}{mass}$$

Then the heat energy Q or E_L supplied to cause a change of state of a solid; mass m is given by $Q = mL_f$

Note: The specific latent heat of fusion of ice is the quantity of heat required to change 1kg of ice at 0°C to 1kg of water at 0°C.

Substance	Specific latent heat of fusion (J/kg)
Ice	335000
Copper	21200
Naphthalene	148000
Lead	26200

Table6.2: Specific latent heats of fusion of various substances

Examples:

1. In an experiment to determine the specific latent heat of fusion, A 100 watt heater is switched on for 300 seconds. When the water resulting from the melting of the ice was weighed, its mass was found to be 0.10kg. What is the specific latent heat of the ice?

   Solution:

   $E_L = mL_f;\ m = 0.10$

   The energy transferred by the heater ($E_L = Pt = 100W \times 300s = 30\ 000J$

   $$L_f = \frac{E_L}{m} = \frac{30000J}{0.10kg} = 300\ 000J/kg$$

2. When a falling hailstone is at a height of 2.00 km its mass is 2.50 g. What is its potential energy? Assuming that all of this potential energy is converted to latent heat during the fall, calculate the mass of the hailstone on reaching the ground. Take the specific latent heat of fusion of ice to be $3.36 \times 10^5 J \cdot kg^{-1}$ and the acceleration due to gravity to be 9.81 m s^{-2}

Solution

Potential energy $= mgh = 2.5 \times 10^{-3} \times 9.81 \times 2 \times 10^3 = 49.05\,J$

The falling hailstone loses potential energy, and this is used to partly melt the hailstone.

$$mL_f = 49.05m \times 3.36 \times 10^5 = 49.05$$

$m = 1.4598 \times 10^{-4}\ kg$ (mass of hailstone that melted)

Total mass of hailstone = 2.50 g

=> Remaining mass that reaches the ground = $2.50 - 0.1458\ g = 2.354\ g$

3. 0.30 kg of ice at 0 °C is added to 1.0 kg of water at 45 °C. What is the final temperature, assuming no heat exchange with the surroundings? Take the specific heat capacity of water to be 4200 J kg^{-1} K^{-1} and the specific latent heat of fusion of ice to be $3.4 \times 10^5\ J\ kg^{-1}$.

Solution

Let q be the final temperature.

Heat lost by water = heat gained in melting the ice + heat gained in warming the ice water

$$m_w c_w \Delta q_w = m_{ice} l_{ice} + m_{ice} c_w \Delta q_{melted\ ice}$$

$$m_w c_w(45 - q) = m_{ice} l_{ice} + m_{ice} c_w \Delta q_{melted\ ice}$$

$$1 \times 4200 \times (45 - q) = (0.3 \times 3.4 \times 10^5) + (0.3 \times 4200 \times q)$$

$$4200\,(45 - q) = 1.02 \times 10^5 + 1260\,q$$

$$1.89 \times 10^5 - 1.02 \times 10^5 = 1260\,q + 4200\,q$$

$$q = 16°\text{C}$$

6.3.2. LATENT HEAT OF VAPORISATION

Latent heat of vaporisation of a substance is the amount of heat energy required (absorbed) by the substance to change its state from liquid to gas at a constant temperature. The specific latent heat of vaporisation of a substance is the heat energy required to change a unit mass of a substance from liquid to gas without change in temperature. The symbol for specific latent heat of vaporisation is L_V and its SI unit is J/kg.

The heat energy Q supplied to cause change of state of mass *m* of a liquid to gas is given by $Q = mL_v$

Note: the specific latent heat of vaporisation of steam is the quantity of heat energy required to change 1 kg of water at 100°C to 1kg of steam at100°C.

Substance	Specific latent heat of vaporisation (J/kg)
Water	2250000
Alcohol	850000
Ether	350000
Chloroform	240200

Table 6.3: Specific latent heats of vaporisation

Note: the change of state in the reverse direction (cooling/ condensing or freezing) involves releasing the same amount of latent heat from the substance. All changes of state occur at a constant temperature (no change of temperature).

Examples:

1. How much heat energy is required to change 500g of water at 100°C to steam?

   Solution:

   First convert g into kg: $500g = 0.500kg$; $L_v\ of\ water = 2\,250\,000 J/kg$ or $2.3 \times 10^6 J/kg$

   $$E_L = mL_v = (0.500kg)(2.3 \times 10^6 J/kg)$$

   $= 1.15 \times 10^6 J$ or $1.2 \times 10^6 J$

2. Calculate the energy released when

   a) 10 g water at 100 °C and

   b) 10 g of steam at 100 °C are each spilt on the hand. Take the specific heat capacity of water to be 4200 J $kg^{-1} K^{-1}$ and the specific latent heat of vaporisation of water to be 2.2 MJ kg^{-1}. Assume that the temperature of the skin is 33 °C.

Solution

a) $E = mc\Delta T = 0.01 \times 4200 \times (100 - 33) = 2814\,J = 2.8\,kJ$

b) The latent heat given out in changing from steam at 100 °C to water at the same temperature is

$E_L = mL_v = 0.01 \times 2.2 \times 106 = 22\,000\,J$

The heat given out when this condensed water drops in temperature from 100 °C to 33 °C is

$$E = mc\Delta T = 0.01 \times 4200 \times (100 - 33) = 2814\,J$$

So, the total heat given out is = 25 kJ

6.3.3. APPLICATION OF LATENT HEAT

Latent heat affects our daily lives in many ways. Here we just mention some of them.

1. **The pressure cooker**

The pressure cooker works by allowing the pressure inside it to be regulated (increased) to increase the boiling point of the water placed in it. It is usually tight sealed to make it air tight preventing steam from escaping until the pressure in the cooker rises to twice the atmospheric pressure. Due to this increase in pressure, the water boils at 120°C causing the cooker to cook much faster than when cooking in a sauce pan.

2. **Refrigerator**

When a liquid changes to gas (vapour), it absorbs latent heat and when the gas changes to liquid (condenses) it releases latent heat. The refrigerator works using this principle.

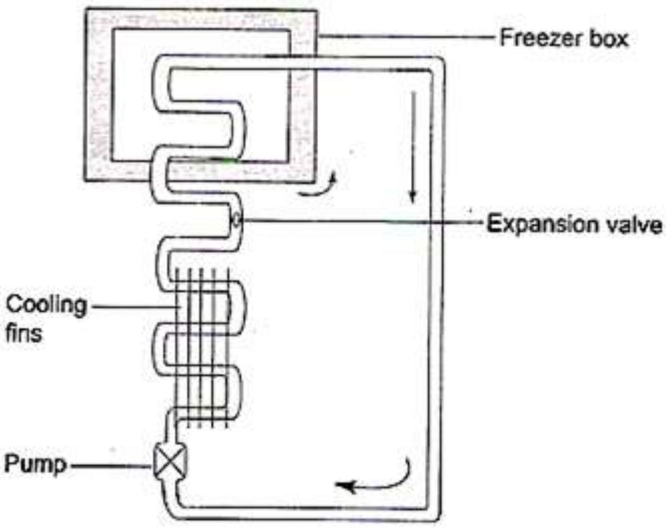

Figure 6.5: A refrigerator

A higher relative liquid whose boiling point is very low about -30°C circulates through a copper pipe surrounding the freezer box. This liquid is the refrigerant (Freon). Around the freezer box the refrigerant circulates absorbing latent heat and is drawn by pump into the pipes on the outside of the freezer. This vapour is then passed into a compressor where it condenses into liquid, releasing the latent heat to the surroundings. To enhance the release of the latent heat copper fins are fitted around the condensing coil. The heat is conducted into copper fins, converted then radiated to the surrounding.

The liquid is then pumped back to the freezer box where it vaporises. This circulation continues. The refrigerator is fitted with an adjustable thermostat that enables the pump metre to vary the high and low temperatures.

The expansion valve reduces pressure in the freezing compartment, so that the refrigerant can vaporise.

EXERCISE 6.1

1. Give the difference between heat capacity and specific heat capacity.

2. Define:
   (a) Temperature
   (b) Heat
3. Give the units of measure of heat and temperature

4. How much heat energy is required to change 2.0kg of ice at 0°C? (**answer:** $\boldsymbol{E_L = 6.6 \times 10.^5 J}$)
5. Air conditioner and evaporative air coolers are commonly used for cooling houses on hot days. An evaporative air cooler blows air at a rate of 6.5kg/min so that the air of a 75m^3 room passes through the machine 4 times every hour. For every 6.5kg of air that passes through the machine 5g of water is evaporated.

Latent heat of water = 2250J/g
Specific heat of air = $100 J/kg \cdot K$

6. Assuming that the thermal energy needed to evaporate the water (latent heat) is entirely extracted from the air flow; calculate the heat transferred to the water from the air flow every minute.
   (a) By how many degrees is the air cooled on each pass through the machine?
   (b) Why is it recommended that
      (i) Evaporative air coolers be operated with a window open
      (ii) Air conditioners be operated with all windows closed?
7. Suggest some energy-saving ways of keeping the insides of a house cool on hot summer days.

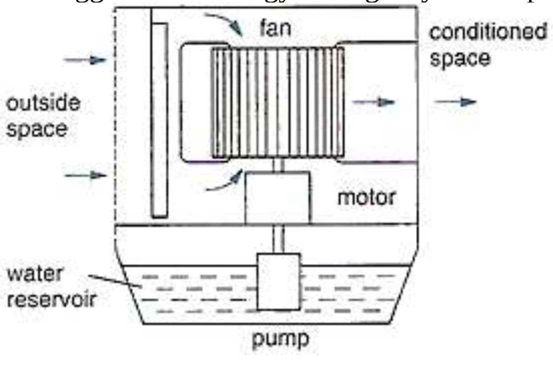

Figure 6.6

8. Water is sometimes stored in a bag of porous material. E.g. canvas, which is hung where it is exposed to a draught of air. Explain why the temperature of the water is lower than that of the air.
9. Explain why the external metal fins of a refrigerator become warm while the refrigerator is in operation. What is the source of this thermal energy?
10. Calculate the energy required to
   (a) Rise the temperature of 1kg of water from 0°C to 100°C
   (b) Change 1kg of water at 100°C to steam. (specific heat of water is 4200J/kgK; L_v = 2300000J/kg)

11. A 125g Pyrex glass mug at 20°C is filled with 200g of tea at 90°C. assuming that all heat lost by the coffee is transferred to the mug, what will be the final temperature of the tea? (**Answer: 83°C)**
12. What will be the final temperature if 1.0kg of water at 20°C is heated by the condensation of 30g of steam at 100°C? (Answer $T_2 = 38.4℃ \, or \, 38℃$)