9 MEASUREMENT OF HEAT ENERGY

SPECIFIC HEAT CAPACITY AND HEAT CAPACITY

Heat is energy transferred as a result of temperature difference between two points of a body. It is also the energy transmitted from a hot object to a cold object. It is the total energy of a body (sum of kinetic and potential energy of a body). The amount of heat energy in a body is measured by its mass if the temperature is constant. This is called thermal energy or the quantity of heat and is measured in joule (J).

OBJECTIVES

At the end of this topic, students should be able to:

- Explain the relationship between the heat supplied to a substance and;
  (i) change in temperature if mass is kept constant;
  (ii) mass if the temperature is constant;
- explain the terms specific heat capacity and heat (thermal) capacity;
- explain why the same mass of different substances supplied with the same heat energy rises in temperature by different amount;
- state the assumptions underlying the experiments involving the measurements of heat quantities;
- solve simple problems using the relation *Q= mcÎ”Î¸* when no change of state is involved.

Heat energy and factors affecting it

Heat is the total energy of a substance. The quantity of heat in a body depends on:

(1) mass of the substance: The heat content of a substance is proportional to its mass if the temperature is kept constant. A bucket of boiling water contains more heat than a cup of boiling water. (Q âˆž m)

(2) rise in temperature of the substance (Î”Î¸): the higher the temperature of a substance, the greater the heat content of the substance. A cup of water at a temperature of 100Â°C contains more heat energy than the same cup of water at 30Â°C.

$$(Q \propto \Delta\theta)$$

(3) ***the nature of the substance:*** If the same mass of copper and water are heated to the same temperature, the heat content of water is higher than the heat content of copper. This shows that the quantity of heat in a body depends on the nature of the substance.

Specific heat capacity (c)

Heat energy possessed by a body is directly proportional to the product of its mass and the change in temperature.

$$Q \propto m\Delta\theta$$

$$Q = mc\Delta\theta$$

The constant c is the **specific heat capacity of the substance/body;** it depends on the nature of the substance.

Specific heat capacity of a substance is the quantity of heat energy needed to change the temperature of a unit mass (1 kg) of a substance by 1 Kelvin.

$$C = \frac{Q}{m\Delta\theta}$$

The SI unit of specific heat capacity c is joule per kilogram per Kelvin (J kg^{-1} K^{-1}). It is also measured in joule per gram per Kelvin (J g^{-1} K^{-1}). Table 8.1 shows the specific heat capacity of some common substances:

S/N	Substance	Specific heat capacity (J $kg^{-1}K^{-1}$)
1	Silver	250
2	Copper	380
3	Brass	380
4	Iron	460
5	Aluminium	880
6	Ice	2100
7	Alcohol	2300
8	Methyl spirit	2400
9	Paraffin wax	2800
10	Water	4200

Table 9.1 Specific heat capacity of some substances

Heat capacity (C)

Heat capacity is the quantity of heat needed to change the temperature of any mass of a substance by 1K.

Heat capacity = Mass of substance Ã— specific heat capacity of the substance

$$C = mc$$

Heat capacity of a substance depends on its mass. Heat energy contained in a given mass of a substance is high if the heat capacity is high. For the same mass of copper and water, the rise in temperature is higher for copper than water when they are given the same amount of heat energy. This is because copper needs less heat energy to increase its temperature. The quantity of heat absorbed or given out by a substance is equal to:

Q = mcÎ” Î¸ Or *Q = CÎ” Î¸*

Worked examples

1. How much heat is needed to increase the temperature of 150g of water from 30Â°C to 50Â°C, if the specific heat capacity of water is 4200 J kg^{-1} K^{-1}?

Solution

Mass of water = 150 g = 0.15 kg

Increase in temperature Î”*Î¸* = 50 – 30 = 20Â°C

Specific heat capacity c = 4200 J Kg^{-1} K^{-1}

Q = mcÎ” Î¸

Q = 0.15 Ã—4200 Ã—20 = 12600 J

2. A copper sphere of mass 200 g is cooled from an initial temperature Ã¨ to 30Â°C. Calculate the value of the initial temperature if the heat energy lost by the sphere is 72000 J. (Specific heat capacity of copper is 400 J Kg^{-1} K^{-1})

Solution

Mass of copper = 200 g = 0.2 kg

Change in temperature Î” Î¸=(Î¸–30)

Specific heat capacity of copper c = 400 J kg K^{-1}

Q = mcÎ” Î¸

72000 = 0.20 Ã— 400 Ã— (Î¸- 30)

72000 = 80(Î¸-30) 800 = 72000 + 2400

Î¸ = 930Â°C.

Heat exchange

Heat energy is exchanged anytime hot and cold substances mix. The hot substance loses heat energy while the cold substance gains heat energy. *Exchange of heat energy will continue until the hot and the cold substances reach an equilibrium temperature. This is the* ***maximum steady temperature*** *of the mixture.* Energy is conserved, if the loss of heat to the surrounding is minimized. The important assumption made in all heat exchange calculation is that:

Total heat energy lost by the hot substance is equal to the total heat energy gained by the cold substance.

To carry out experiments on heat exchange in the laboratory, **calorimeters** are used. Calorimeters are vessels made from metals like copper or aluminium. It is designed to ensure that heat loss to the surroundings is minimized. Exchange of heat energy with the surroundings is possible by **radiation, conduction, convection** and **evaporation.** Calorimeters are designed to reduce heat lost to the environment by any of this modes of heat transfer.

â€¢ Heat loss by radiation is reduced by polishing or silvering the inner and outer calorimeter.

â€¢ Heat loss by conduction is reduced by surrounding the inner calorimeter with a bad conductor like wool or cotton. This is called **lagging.**

â€¢ Heat lost by convection and evaporation is reduced by covering the calorimeter with a lid.

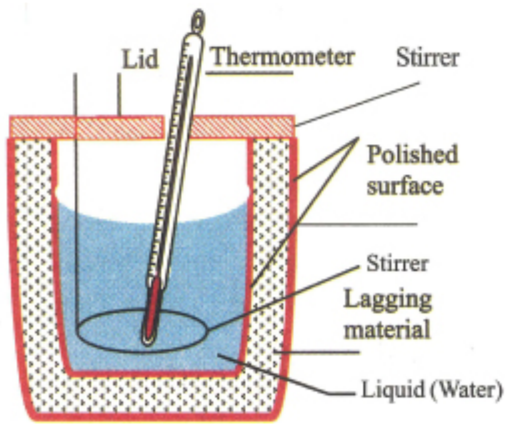


Figure 9.1: Calorimeter

Worked examples

3. An aluminium solid at 100Â°C is dropped into a copper calorimeter of mass 60g containing 80 g of water at 20Â°C. Calculate the mass of the aluminium solid if the steady maximum temperature of the mixture is 30Â°C. {*Specific heat capacity of copper, aluminium and water are 400, 900 and 4200 J Kg^{-1} K^{-1} respectively*}

Solution

Heat lost by aluminium $Q_a = m_a c_a \Delta\theta_a$

Heat gained by calorimeter $Q_c = m_c c_c \Delta\theta_c$

Heat gained by water $Q_w = m_w c_w \Delta\theta_w$

Heat lost by hot aluminium = Heat gained by calorimeter and water

$m_a c_a \Delta\theta_a = m_c c_c \Delta\theta_c + m_w c_w \Delta\theta_w$

$m_a \times 900 \times 70 = (0.06 \times 400 \times 10) + (0.08 \times 4200 \times 10)$

$63000\ m_a = 240 + 3360$

$$m_a = \frac{3600}{63000} = 0.057kg$$

2. (a) Explain the meaning of the statement, â€œthe specific heat capacity of water is 4200J kg^{-1}â€;

(b) 500 g of aluminium block at a temperature of 650Â°C is dropped into a copper calorimeter of mass 100 g containing 800 g of water at 30Â°C. Calculate the maximum temperature of the mixture. {*Specific heat capacity of water, copper and aluminium are 4200 J kg^{-1} K^{-1}, 400 J kg^{-1} K^{-1} and 900 J kg^{-1} K^{-1} respectively.*}

Solution

(a) The statement means that 4200 J of heat energy is needed to increase the temperature of 1 kg of water by 1K.

(b) Heat lost by aluminium Q_a =$m_a c_a$Î”Î¸$_a$

Heat gained by calorimeter Q_c = $m_c c_c$Î”Î¸$_c$

Heat gained by water Q_w = $m_w c_w$ Î”Î¸

Heat lost by hot aluminium = Heat gained by copper calorimeter and water

$m_a c_a$ Î” Î¸$_a$ = $m_c c_c$ Î” Î¸$_c$+ $m_w c_w$Î” Î¸$_w$

0.5Ã—900Ã— (650 -Î¸) = 0.1Ã—400Ã—(Î¸- 30) + 0.8Ã—4200 (Î¸-30)

450(650 – Î¸) = 40(Î¸- 30) + 3360(Î¸ – 30) 292500 – 4500 = 400- 1200 + 33600- 100800

38500=39450Î¸

Î¸= 102.5Â°C

3. When 342000 J of heat energy is added to a material of mass 15 kg the temperature rises from 30Â°C to 90Â°C. Calculate the heat capacity of the material.

Solution

Quantity of heat = Thermal capacity x temperature rise (Q) = Cp)

$Q = C\times\Delta\theta$

$342000 = C \times 60$

$$C = \frac{342000}{60} = 5700\ J\ K^{-1}$$

Measurement of specific heat capacity of solid by method of mixture

Apparatus: A thin walled calorimeter, stirrer, thermometer, metal solid, tripod stand, Bunsen burner, a beaker with water, beam balance and thread.

Method:

(i) Use the beam balance to carry out the following procedures:

â€¢ Weigh the solid provided and record its mass *(m_s);*

â€¢ Clean the calorimeter, put the stirrer inside, weigh and record the mass of the empty calorimeter and stirrer *(m_c)*;

â€¢ Fill the calorimeter with water enough to cover the solid, weigh again and record the mass of calorimeter and water *(m).* Find the mass of water by evaluating m_w = *(m – m_s).* Measure and record the initial temperature (Î¸$_1$) of water and calorimeter.

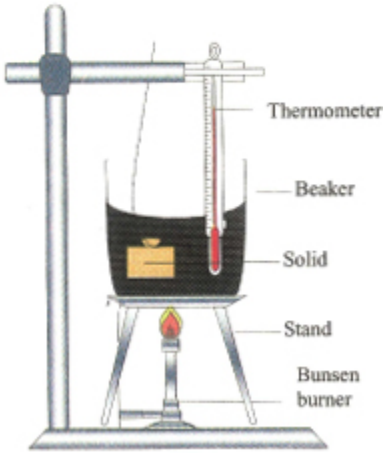


Figure 9.2: Determination of specific heat capacity of a solid by method of mixture

(ii) Use the thread to suspend the solid in a beaker of water, allow standing for few minutes until the solid and water attain an equilibrium temperature (Î¸$_1$). Record this temperature *Î¸*$_1$ as the initial temperature of solid.

(iii) Put the beaker and its content on the tripod stand and perform the following procedures:

- â€¢ Heat the beaker and its content gently till the water boils for several minutes to allow the solid to reach the same temperature as the boiling water;
- â€¢ Measure the temperature of the boiling water and record it as the temperature of the solid (Î¸$_2$=100Â°C);
- â€¢ Transfer the solid quickly to the calorimeter after shaking off water droplets from the solid;
- â€¢ Stir the water gently to maintain uniform temperature and record the highest steady temperature of the mixture (Î¸).

Calculations:

Mass of water $m_w = (m - m_c)$

Change in temperature of solid Î”Î¸$_s$ = (100 – Î¸$_2$)

Change in temperature of water Î”Î¸$_w$ = (*Î¸*$_2$ – *Î¸*$_1$) Change in temperature of calorimeter Î”*Î¸*$_w$= (*Î¸*$_2$- *Î¸*$_1$)

Heat lost by hot solid = $m_s c_s$(100 – *Î¸*$_2$)

Heat gained by calorimeter = $m_c c_c$(*Î¸*$_2$ – *Î¸*$_1$)

Heat gained by water = $m_w c_w$(*Î¸*$_2$ – *Î¸*$_1$)

Heat lost by solid = Heat gained by calorimeter and water

$m_s c_s$(100 – *Î¸*) = $m_w c_w$(*Î¸*$_2$ – *Î¸*$_1$)+ $m_c c_c$(*Î¸*$_2$ – *Î¸*$_1$)

Precautions

1. Transfer the hot solid quickly from the boiling water to the calorimeter and the lid covered immediately to reduce loss of heat to the surrounding.
2. Drop the hot solid gently into the calorimeter to avoid splashing of water.

3. Stir the calorimeter and its content continuously to keep the temperature constant.
4. Lagg the calorimeter well to reduce heat exchange with the surroundings.

Measurement of specific heat capacity of liquid by method of mixture

Apparatus: A thin walled calorimeter, stirrer, thermometer, liquid (water), tripod stand, Bunsen burner, a beaker with water, beam balance and thread.

Method:

(i) Clean the calorimeter, put the stirrer inside, weigh and record the mass of the empty calorimeter and stirrer (m_c);

(ii) Put the calorimeter inside a lagging material and measure its temperature *Î¸*$_{c}$;

(iii) Heat some quantity of water in a beaker, stir continuously to keep the temperature uniform, measure and record the temperature of the hot water Î¸$_{w}$;

(iv) Pour the hot water into the calorimeter until it is half filled, stir and measure the final steady temperature ***(*Î¸*)*** of the mixture.

(v) Remove the calorimeter from its lagging; allow cooling to room temperature, measure and record the mass of the calorimeter and water with beam balance.

Calculations:

Fall in temperature of water Î”Î¸$_{w}$ = *Î¸*$_{w}$ – *Î¸*

Rise in temperature of calorimeter Î”*Î¸*$_{c}$ = *Î¸*$_{c}$ – *Î¸*

Heat lost by hot water = m_w c_w *(Î¸*$_{w}$ – *Î¸)*

Heat gained by calorimeter = $m_c c_c$(Î¸$_{c}$ – Î¸)

Heat lost by hot water = Heat gained by calorimeter

m_w c_w (Î¸$_{w}$ – Î¸) = $m_c c_c$(Î¸$_{c}$ – Î¸)

Electrical method of measuring specific heat capacity of a liquid

Electrical energy

Electrical energy is converted to heat energy when electric current flows through a heating coil.

The quantity of heat produced is given by:

Q = IVt {I = *current, V = voltage and t = time}*

The heat produced is used to warm the water and increase its temperature.

Apparatus: Lagged calorimeter, heating coil, liquid (water), ammeter, voltmeter, rheostat, key, battery, stop clock and thermometer.

Method

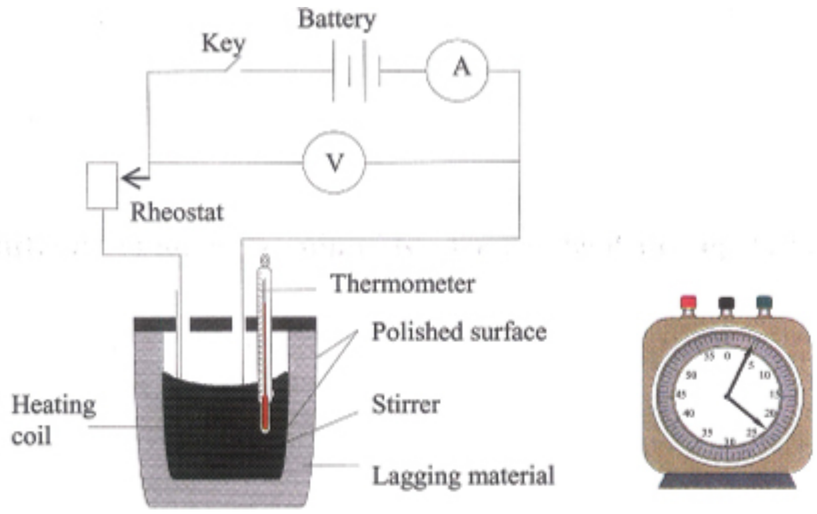


Figure 9.3: Measuring specific heat capacity of liquid

(i) Clean the calorimeter put the stirrer inside, weigh and record the mass of the empty calorimeter and stirrer *(m_c)*;

(ii) Pour the liquid into the calorimeter until it is half filled, stir and measure the temperature *(Î¸$_1$)* of the liquid and calorimeter.

(iii) Switch on the current by closing the key and at the same time start the stop clock. Measure and record the current through the ammeter and the voltage indicated by the voltmeter.

(iv) The liquid is stirred continuously to keep the temperature constant. The current is switched off after t seconds and the final steady temperature of the liquid and calorimeter measured (*Î¸*$_2$).

Calculations

Heat given out by the heating coil = IVt

Heat gained by liquid = $m_l c_l$*Î” Î¸*$_l$

Heat gained by calorimeter = $m_c c_c$*Î” Î¸*$_c$

Heat given out by heating coil = Heat gained by calorimeter and water

$IVt = m_l c_l$*Î” Î¸*$_l$+ $m_c c_c$*Î” Î¸*$_c$

Precautions

1. To compensate for heat exchange with the surroundings, the liquid is first cooled to about 5Â°C below room temperature and heating continued until the temperature rises to about 5Â°C above the room temperature.
2. The current flowing through the coil is kept constant through out the heating.
3. The liquid is stirred continuously to ensure uniform temperature throughout the volume of the liquid.
4. The calorimeter should be well lagged.

Electrical method of measuring specific heat capacity of a solid

Apparatus: Lagged calorimeter, heating coil, metal block, ammeter, voltmeter, rheostat, key, battery, stop clock and thermometer.

Method:

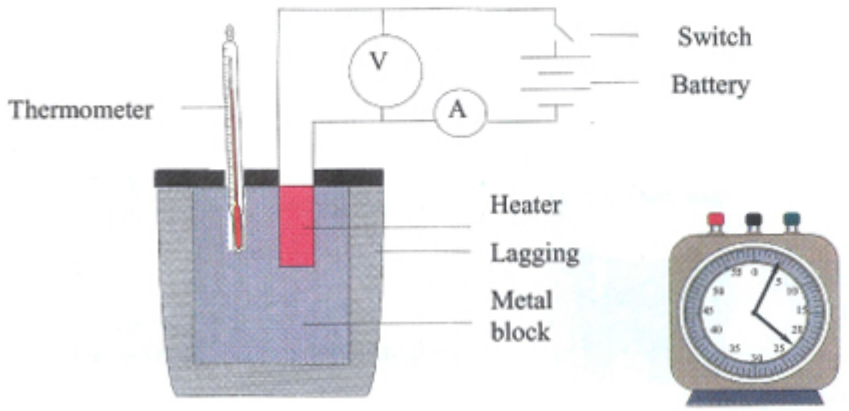


Figure 9.4: Electrical method of measuring specific heat capacity of a solid

The specific heat capacity of a metal block can be determined electrically as shown in Figure 8.4. Two holes are drilled on the block and lubricated with oil to allow the heater and the thermometer make good thermal contact with the block. Exchange of heat with the surroundings is reduced by lagging.

The current is switched on and kept constant throughout the heating process and at the same time the stop clock is started. The current is allowed to flow for some minutes before it is switched off before the readings of the ammeter and voltmeter are taken.

Calculations:

Heat given out by the heating coil = *IVt*

Heat gained by solid = $m_s c_s$*Î” Î¸*$_s$

Heat given out by heating coil = Heat gained by the solid block

IVt = $m_s c_s$*Î” Î¸*$_s$

Worked examples

1. An electric kettle of mass 0.5 kg rated 1 kW contains liquid of mass 1.5 kg. Calculate the specific heat capacity of the liquid if it is heated from 30Â°C to 80Â°C in 5minutes. *{Specific heat capacity of the material of the kettle is 900 J kg^{-1} k^{-1}}.*

Solution

Power *P* of the kettleâ€™s heater = *IV* = 1 000 W

Heat given out by the heater of the kettle: Q_1 = *Pt* =1 000 Ã— 5 Ã— 60 = 300 000 J

Heat absorbed by the material of the kettle: Q_2 = $m_k c_k$Î”Î¸$_k$ = 0.5Ã—900Ã—50 = 22 500 J

Heat gained by liquid: Q_3 = $m_l c_l$Î”Î¸$_1$ = 1.5Ã—c$_1$Ã— 50 = 75 c$_1$

Heat given out by the heating coil = Heat gained by the liquid and kettle

$$Pt = m_k c_k \Delta\theta_k + m_l c_l \Delta\theta_l$$

$$300000 = 22500 + 75c_l$$

$$c_l = \frac{30000 - 22500}{75} = \frac{277500}{75} = 3700\ J\,kg^{-1}\,K^{-1}$$

2. Calculate the time it takes 1000 W heater to increase the temperature of 30 kg of copper block from 25Â°C to 125Â°C, if the specific heat capacity of copper is 400 J kg^{-1} K^{-1}.

Solution

Power *P* of the heater = *IV* = 1000 W

Heat given out by the heater Q_l= *Pt* = 1000 *t.*

Heat absorbed by copper block Q_2 = $m_c c_c$Î”Î¸$_c$ = 30Ã—400Ã—100 = 1200000 J

Pt = $m_c c_c$Î”Î¸$_c$

1000t= 1200000

t = 1200 seconds = 20 minutes

Conversion of potential energy to heat energy

The energy of water at the top of waterfalls and dams is potential energy. The potential energy of the water is transformed to kinetic energy as the water falls. At the bottom of the waterfall, the kinetic energy is changed to heat energy, therefore the temperature of water at the base of the waterfall is higher than the temperature at the top. The conversion from potential energy to heat energy can be used to find the specific heat capacity of a substance.

Calculations

Potential energy at the top = *mgh*

Gain in heat energy at the base = $m_s c_s$Î”Î¸$_s$

Loss in potential energy at the top = Gain in heat energy at the base

mgh = $m_s c_s$Î”Î¸$_s$

Worked example

A brass sphere of mass 50 kg and specific heat capacity 380 J kg^{-1} K^{-1} dropped from a height of 500 m. What is the rise in temperature of the sphere if all the potential energy at the top is transformed to heat energy?

Solution

Potential energy of the sphere at the top E_p = *mgh* = 50 Ã— 10 Ã— 500 = 250000 J

Gain in heat energy *Q* = $m_s c_s$*Î”Î¸$_s$* =50Ã—380Ã—Î” Î¸$_s$

Loss of potential energy = Gain in heat energy

mgh = $m_s c_s$*Î”Î¸$_s$*

50 Ã— 10Ã—500 = 50Ã—380Ã—Î” Î¸$_s$

250000= 19000Î” Î¸$_s$

Î” Î¸$_s$ = 13.2Â°C

Significance of specific heat capacity

(i) Land and sea breeze

The same mass of water (specific heat capacity = 4200 J kg^{-1} K^{-1}) needs more heat to increase its temperature by 1Â°C compared to the soil (specific heat capacity = 800 J kg^{-1} K^{-1}). During the day, the temperature of the land rises more than that of water causing a current of hot air to move from the land to the sea while cool breeze blows from the sea to the land. Land breeze (cool air) blows from the land to the sea in the night.

(ii) Choice of liquid coolant

Liquid with high specific heat capacity like water are used as coolants in car radiators and heat exchangers. This is because more heat energy is required to increase their temperature.

Summary

â€¢ The heat content of a body depends on the mass of the substance, rise in temperature of the substance *(Î”Î¸)* and the nature of the substance.

â€¢ The specific heat capacity of a substance is the quantity of heat energy needed to change the temperature of a unit mass (1 kg) of a substance by 1 Kelvin.

â€¢ Heat capacity is the quantity of heat needed to change the temperature of any mass of a substance by 1 K.

â€¢ In every heat exchange, if there is no loss of heat to the surroundings, the total heat energy lost by the hot substance is equal to the total heat energy gained by the cold substance.

Practice questions 9a

1. (a) State the three factors on which the rise in temperature of a substance depends.

   (b) Calculate the quantity of heat absorbed by the following materials:

   (i) 50 g of solid copper when its temperature increases from 25Â°C to 250Â°C;

   (ii) When 6.3 kg of aluminium ball is heated from 32Â°C to 102Â°C;

   (iii) To raise the temperature of 2.2 kg of water through 60Â°C.

   (Specific heat capacities of copper, aluminium and water are 400 J kg^{-1} K^{-1}, 900 J kg^{-1}K^{-1} and 4200 J kg^{-1} K^{-1} respectively}

2. (a) Explain the meaning of the term **specific heat capacity** of a substance.

(b) Describe an experiment to determine the specific heat capacity of a copper cylinder using method of mixture.

(c) State two precautions you should observe to ensure accurate result.

(d) A copper block of mass 100 g at a temperature of 150Â°C is dropped into a copper calorimeter of mass 40 g containing 80 g of water at 30Â°C. Calculate the steady final temperature of the mixture assuming no heat is lost to the surroundings. {Specific heat capacity of copper and water are 400 J kg^{-1} K^{-1} and 4200 J kg^{-1} K^{-1} respectively}

3. (a) What do you understand by the statement that the **specific heat capacity of aluminium is 900 J kg^{-1}K^{-1}?**

(b) Aluminium block of mass M kg initially at a temperature of 100Â°C is dropped into a vessel containing 60 g of water at 20Â°C. The maximum steady temperature of the water and the aluminium block is 28Â°C; calculate the mass of the aluminium block if the specific heat capacity of the vessel is negligible. {Specific heat capacity of water and aluminium are 4200 J kg^{-1} K^{-1} and 900 J kg^{-1} K^{-1} respectively}

4. (a) Define heat capacity and specific heat capacity of a substance.

(b) A material of heat capacity 1140 J kg^{-1} and specific heat capacity 380 J kg^{-1} K^{-1} heated from 25Â°C to 75Â°C. Calculate:

(i) the mass of the substance;

(ii) the quantity of heat absorbed.

5. (a) Define specific heat capacity of a body.

(b) Describe an experiment to find the specific heat capacity of a liquid.

(c) It takes 30 minutes for an electric kettle rated 2000 W to boil a certain quantity of water at 30Â°C. If the mass of the kettle and its specific heat capacity are 1.2 kg and 900 J kg^{-1} K^{-1} respectively, calculate:

(i) the quantity of heat produced by the heater;

(ii) the mass of water in the kettle.

6. An immersion heater supplies heat at the rate of 500 J s^{-1}:

(i) What is the quantity of heat produced in 25 minutes?

(ii) If all the heat energy is given to a block of brass of mass 3 kg initially at 30Â°C, what is the rise in temperature? {specific heat capacity of brass is 380 J kg^{-1} K^{-1}}

LATENT HEAT

Heating a substance does not always increase its temperature. If heat is supplied to a block of ice at 0Â°C, it melts (change of state) and becomes water at the same temperature (0Â°C). A thermometer dipped in the melting ice does not show an increase in temperature despite the fact that heat energy is being supplied to it. The constant reading of the thermometer does not indicate that energy is not given to the ice while it melts. ***The heat supplied to the ice during the process of melting is called latent or hidden heat.*** Latent heat is used to break the bonds between molecules and to push them apart. It does not increase the kinetic energy of the molecules therefore the temperature remains constant.

OBJECTIVES

At the end of this topic, students should be able to:

- explain the meaning of latent heat of fusion and vaporization:
- determine the melting point of a solid;
- determine the melting point of a given liquid;
- list the effects of impurities and pressure on
  (i) the melting point of a solid (ice)
  (ii) the boiling point of a liquid.
- solve simple problems involving latent heat;
- distinguish between evaporation and boiling and explain sublimation;
- explain the working principles of common devices such as refrigerator, air conditioner and pressure cooker.

Specific latent heat of fusion

Specific latent heat of fusion is the heat energy needed to change 1kg of a solid to liquid at a constant temperature.

Heat absorbed = Mass Ã— Specific latent heat

$$Q = ml_f$$

Where l_f is the specific latent heat of fusion. The unit of specific latent heat of fusion is joule per kilogram (J kg^{-1}) or joule per gram (J g^{-1}). The specific latent heat fusion of ice is 336000 J kg^{-1} or 336 J g^{-1}. *This means that 336000 J is needed to melt completely 1 kg of ice.*

Latent heat of fusion

Latent heat of fusion is the heat energy needed to change any given mass of a solid to liquid at a constant temperature.

Worked examples

1. Given that the latent heat of fusion of ice is 336000 J kg^{-1}, the specific heat capacity of ice and water are 2100 J kg^{-1} $K^{-1}$and 4200 J kg^{-1} K^{-1} respectively, calculate the heat needed to:
   (a) melt 250 g of ice at 0Â°C;
   (b) change 2 kg of ice at 0Â°C to water at 30Â°C;
   (c) change 1.2 kg of ice at -20Â°C to water at 0Â°C.

Solution

(a) Mass of ice 250g = 0.25kg, l_f= 336000 J kg^{-1}

$Q = ml_f$= 0.25 Ã— 336000 = 84000 *J*

(b) Two stages are involved in this change of state. Firstly the ice melts and becomes water at 0Â°C, and lastly water gains heat energy as the temperature increases from 0Â°C to 30Â°C.

$Q = ml_f + mc_w$*Î” Î¸*

Q = 2Ã—336000 + 2Ã—4200Ã—30

Q = 672000 + 252000

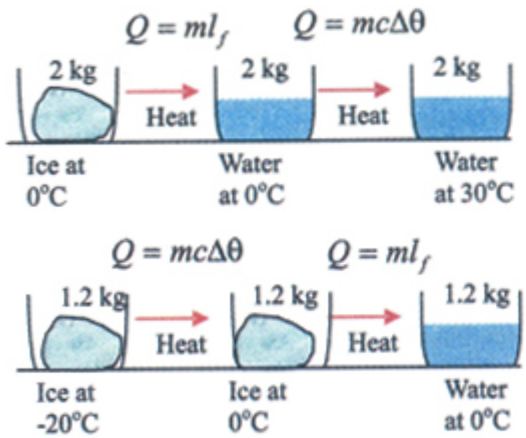
Q =924000 *J*

(c) *Q* = mcÎ” Î¸ + ml_f

Q = 1.2Ã—2100Ã—20 + 1.2Ã—336000

Q = 50400 + 403200

Q = 453600 *J*



2. Ice of 0.1 kg at 0Â°C is added to 1.0 kg of water at 30Â°C and stirred until all the ice melts completely. If the temperature of the mixture is 20Â°C, calculate the specific latent heat of fusion of the ice.

{Specific heat capacity of water = *4200 J kg^{-1} K^{-1}*}

Solution

Heat lost by water = Heat gained by the block of ice

$$m_w c_w \Delta\theta = m_i c_i \Delta\theta_i + m_i l_f$$

$$1.0 \times 4200 \times 10 = 0.1 \times 4200 \times 20 + 0.1 l_f$$

$$42000 = 8400 + 0.1 l_f$$

$$42000 - 8400 = 0.1 l_f$$

$$l_f = \frac{33600}{0.1} = 336000\ J\ kg^{-1}$$

3. A copper cup of mass 0.5 kg contains 1.5 kg of water at 30Â°C. If the cup and its content are placed in a deep freezer at -10Â°C, find the total heat lost by the cup and water to reach the same

temperature as the deep freezer. {Specific heat capacity of water = 4200 J kg^{-1} K^{-1}, specific latent heat of fusion of ice = 336000 J kg^{-1} and specific heat capacity of copper = 400 J kg^{-1} K^{-1}} specific heat capacity of ice = 2100 J Kg^{-1} K^{-1}

Solution

Copper loses heat in only one stage; from 30Â°C to -10Â°C. Heat lost by copper *Q_1 = $m_c c_c$Î”*Î¸$_c$ Heat lost by copper = 0.5Ã—400Ã—40 = 8000 J.

Water lost heat in three stages;

(i) Stage one; to cool from 30Â°C to 0Â°C

(ii) Stage two; to freeze to ice at 0Â°C;

(iii) Stage three; ice cools from 0Â°C to -10Â°C.

Q_2 = $m_w c_w$ Î” Î¸$_w$ + ml_f+ $m_i c_i$Î” Î¸$_i$

Q_2= 1.5Ã—4200Ã—30+1.5Ã—336000+1.5Ã—2100Ã—10

Q_2= 189000+504000+31500

Q_2 = 724500 J

Total heat lost Q = Q_1 + Q_2 = 8000 + 724500 = 732500 J.

Determination of specific latent heat of fusion of ice

Apparatus: Calorimeter, thermometer, blocks of melting ice, beaker of water, blotting paper and Bunsen burner.

Method

(i) Clean the calorimeter, put the stirrer inside, weigh and record the mass of the empty calorimeter and stirrer *(m_c);*

(ii) Pour water into the calorimeter until it is half filled and weigh the calorimeter a second time to determine the mass of water *(m_1);*

(iii) Warm the water until the temperature is about 5Â°C above room temperature, stir and record the temperature Î¸$_1$;

(iv) Use a blotting paper to dry the melting ice and add to the water in the calorimeter. Stir until the ice melts completely before adding another piece of ice;

(v) Keep adding ice and stirring until the temperature falls to about 5Â°C below the room temperature. Measure and record the temperature *Î¸$_2$.*

(vi) The calorimeter is weighed a third time to determine the mass of melted ice *(m_2).*

Calculations

Mass of water *m_w = (m_l – m_c)*

Mass of ice melted *m_i = (m_l -m_c)*

Heat gained by ice *Q = ml_f + $m_i c_w$Î” Î¸$_i$*

Heat lost by water *Q = $m_w c_w$Î”Î¸$_w$*

Heat lost by calorimeter *Q = $m_c c_c$Î”Î¸$_c$*

Heat lost by water and calorimeter = Heat gained by the block of ice

m_wc_wÎ” Î¸$_w$ + m_cc_cÎ” Î¸$_c$ =ml_f + m_ic_wÎ”Î¸$_i$

Precautions

(i) The ice is dried with blotting paper before it is added to the water in the calorimeter.

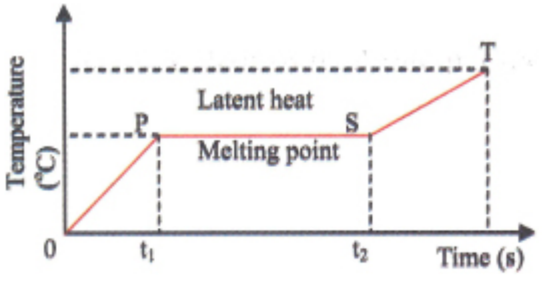
(ii) The calorimeter and its content are stirred continuously to ensure even temperature.

(iii) The calorimeter and the water inside are warmed slightly above the room temperature and cooled below the room temperature by the same degree to compensate for exchange of heat with the surroundings.

Melting and freezing points of a substance

The melting point of a substance is the constant temperature at which it changes state from solid to liquid.

Ice melts at a constant temperature (0Â°C). The heat supplied during the change of state is not registered by a thermometer and is called **latent heat of fusion**. This is the flat portion (PS) of the heating curve.



The flat portion of the heating curve also represents the **melting point** of the substance. When heat is removed from water, the temperature steadily falls until it freezes at 0Â°C.

The constant temperature at which a substance changes state from liquid to solid is the freezing point of the substance.

Factors affecting melting point of a substance

The melting point of a pure substance can be changed in two ways: by adding impurities and changing the **pressure** on it.

(i) Impurities alters the melting point of a substance: Addition of salt and liquids with low boiling point to ice will lower its melting point. Instead of ice melting at 0Â°C, it will melt at a temperature lower than 0Â°C. The degree of lowering of the melting point depends on the concentration of the impurity added. Adding salt to water in the ratio of 1:10 will lower the freezing or melting point of water to -6Â°C. In cold countries, methyl alcohol and glycerine are mixed with water in car radiators to prevent it from freezing. This is because they lower the freezing point of water.

(ii) Pressure changes (or alters) the melting point and freezing points of a substance: The melting point of a substance is altered if the pressure on it is changed. For substances which expand on freezing (contracts on melting), their melting point is lowered if the pressure on them is increased. Ice for example, expands on freezing; therefore, its melting point is less than 0Â°C when the pressure on it is increased.

Effect of pressure of the melting point of ice

We can demonstrate the effect of pressure on melting point of ice as follows:

â€¢ Place a big block of dry ice on two supports.

â€¢ Apply pressure at a point on the ice by placing a thin wire with two big weights at its ends on the ice.

â€¢ Observe that the wire passes through the ice without cutting it into two halves.

The wire exerts high pressure on the ice at the point of contact. The ice under the wire melts because the high pressure at the point of contact lowers its melting point. The wire passes through the water formed, pressure is reduced and the water above the wire refreezes. The melting of ice and refreezing of water is called **regelation.** Regelation explains why the wire could pass through the ice without cutting it into two parts.

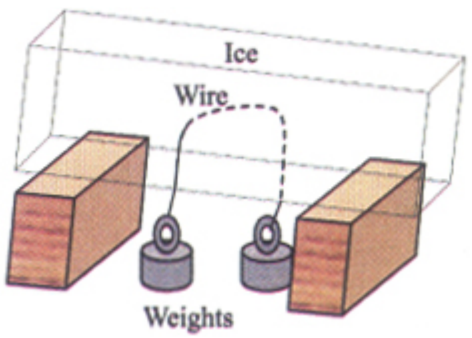


Figure 9.5: Demonstrating pressure effect on melting point

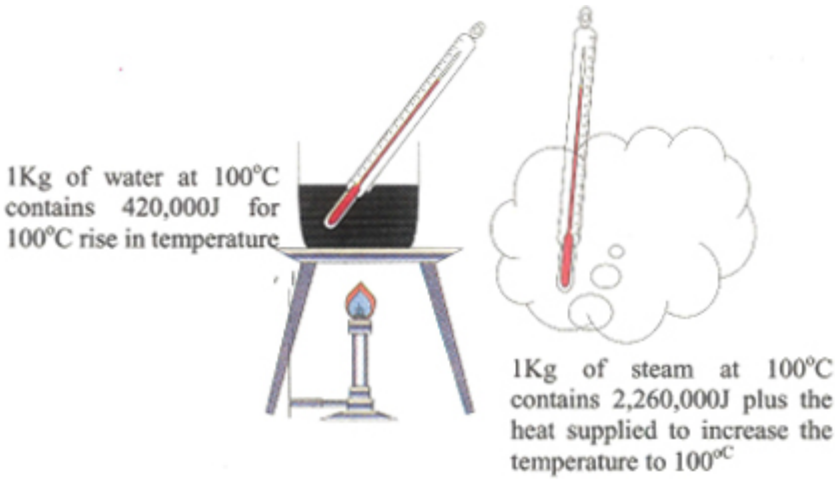
Two small pieces of ice can fuse or stick together by exerting pressure on them. The high pressure at the point of contact reduces the melting point of the ice making the ice to melt. If the pressure at the point of contact is removed, the water formed between the ice blocks refreezes to join the two pieces of ice together.

Latent heat of vaporisation

If energy is constantly supplied to water, it boils when the temperature is 100Â°C. The temperature of the boiling water remains constant at 100Â°C as water changes to steam. If enough energy is supplied to the water, it changes to steam in a process known as **vaporization.** Vaporisation of water occurs at a constant temperature of 100Â°C. The heat energy supplied as water changes to steam is not registered by the thermometer and is called **latent heat of vaporization.**

Specific latent heat of vaporisation

The specific latent heat of vaporization is the heat energy needed to convert 1 kg of a liquid to vapour at constant temperature.



The specific latent heat of vaporization of steam is about 2,260,000 J kg^{-1}; ***that is the energy needed to convert completely 1 kg of water at boiling point to steam at the same temperature is 2,260,000 J.*** On the other hand, if 1 kg of steam is condensed to water without change of temperature 2 260 000 J is given out. ***The energy given out by 1 kg of steam to condense to water is much greater than the energy absorbed by 1 kg of water to increase its temperature by 100Â°C.*** This is why steam burns is more dangerous than hot water burns.

The quantity of heat energy absorbed or radiated by a substance to change its state is given by:

Heat energy = Mass Ã— specific latent heat of vaporization

$$Q = ml_v$$

The unit of specific latent heat of vaporization is joule per kilogram (J kg^{-1}) or joule per gram (J g^{-1}).

Worked examples

1. Calculate the heat absorbed in each of the following cases:

(a) 300 g of water at 100Â°C is vaporised completely;

(b) 800 g of water at 70Â°C is converted to steam at 100Â°C;

(c) 1 kg of ice at 0Â°C is converted to steam at 100Â°C.

{Specific heat capacity of water = *4 200 J* kg^{-1} K^{-1}, specific latent heat of fusion of ice = *336 000 J* kg^{-1} and specific latent heat of vaporization of steam = *2 260 000 J* kg^{-1}}

Solution

(a) $Q = ml_v$

l_v = 2 260 000 J kg^{-1}, m = 300 g = 0.3 kg

Q = 0.3 Ã— 2 260 000 = 678000 J

(b) The total heat absorbed is the sum of heat absorbed by water from 30Â°C to 100Â°C and the heat absorbed by water to change to steam at 100Â°C.

Q = $m_w c_w$Î”Î¸$_w$ + ml_v

Q = 0.8Ã—4200Ã—30 + 0.8Ã—2 260 000

Q = 100 800 J + 1 808 000 J

Q = 1 908 800 J

(c) The heat is absorbed in three stages: heat absorbed to melt the ice at 0Â°C, the heat absorbed from 0Â°C to 100Â°C and the heat absorbed to change the water to steam at 100Â°C.

Q = $m_i l_i$ + $m_w c_w$ Î”Î¸$_w$ + ml_v

Q = 1 Ã—336 000+1 Ã—4 200x 100+1 Ã—2 260 000

Q = 336 000+420 000+2 260 000

Q = 3 016 000 J.

2. Solid copper of mass 500 g at a temperature of Î¸Â°C is dropped into a vessel containing 300 g of water at 40Â°C. If the mass of water that boils away is 20 g, calculate the initial temperature of the copper solid. Neglect the heat capacity of the vessel.

{Specific heat capacity of water = *4200 J* kg^{-1} K^{-1}, specific heat capacity of copper = *400* Jkg^{-1} and specific latent heat of vaporization of steam = *2 260 000 J* kg^{-1}}

Solution

Mass of copper solid m_c = 500 g = 0.5 kg

Mass of water m_w = 300 g = 0.3 kg

Mass of steam m_s= 20 g = 0.02 kg

Heat lost by copper = $m_c c_c$*Î” Î¸$_c$ = 0.5Ã—400(Î¸ - 100)*

Heat gained by water = $m_w c_w \Delta\theta_w + m_s l_v = 0.3\times 4\,200\times 60 + 0.02\times 2\,260\,000 = 75\,600 + 45\,200$
$= 120\,800$ J

Heat lost by solid copper = Heat gained by water

$m_c c_c \Delta\theta_c = m_w c_w \Delta\theta_w + ml_v$

$0.5\times 400(\theta - 100) = 120\,800$ J ==> $200(\theta - 100) = 120\,800$ J

$$(\theta - 100) = \frac{120800}{200} = 604^{\circ}\mathrm{C}$$

$\theta = 604^{\circ}\mathrm{C} + 100^{\circ}\mathrm{C} = 704^{\circ}\mathrm{C}$

3. If the specific heat capacity of water = *4200 J* kg^{-1} K^{-1}, specific heat capacity of copper = *400 J* kg^{-1}, specific latent heat of ice = *336 000 J* kg^{-1} and vaporization of steam = *2 260 000 J* kg^{-1}, calculate the mass of steam that will pass into the calorimeter of mass 60 g containing 80 g of water and 10 g of ice at 0Â°C to raise the temperature to 30Â°C. Neglect heat lost to the surroundings.

Solution

Heat lost by steam $= m_s l_s + m_w c_w \Delta\theta_w = m_s \times 2260000 + m_s \times 4200 \times 70 = 2\,554\,000\; m_s$

Heat gained by water and calorimeter $= m_c c_c \Delta\theta_c + m_w c_w \Delta\theta_w = 0.08 \times 4200 \times 30 + 0.06 \times 400 \times 30$

$= 10\,800$ J

Heat gained by ice $= ml_f + m_i c_i \Delta\theta_i = 0.01 \times 336\,000 + 0.01 \times 4\,200 \times 30 = 4620$ J

Heat lost by steam = Heat gained by water, ice and calorimeter

$m_s l_s + m_w c_w \Delta\theta_w = m_c c_c \Delta\theta_c + m_w c_w \Delta\theta_w + ml_f + m_i c_i \Delta\theta_i$

$2\,554\,000 m_s = 10\,800 + 4\,620$

$2\,554\,000 m_s = 15420$

$$m_s = \frac{2554000}{15420} = 0.006\ kg$$

Determination of specific latent heat of steam

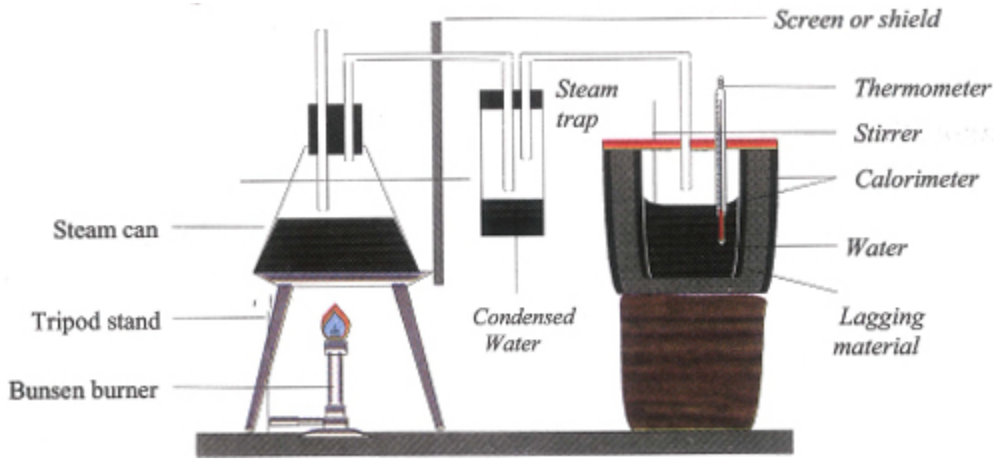


Figure 9.6: Determination of latent heat of varporisation of steam

Apparatus: Calorimeter, thermometer, beaker of water, steam can, steam trap, beam balance, tripod stand, screen and Bunsen burner.

Method

(i) Clean the calorimeter and put the stirrer inside, weigh and record the mass of the empty calorimeter and stirrer (m_c);

(ii) Pour water into the calorimeter until it is half filled, 5Â°C below room temperature record the temperature (*Î¸*$_1$) and weigh the calorimeter a second time to determine the mass of water (m_1).

(iii) Place the calorimeter in its lagging material and pass dry steam into the water in the calorimeter until the temperature rises by 5Â°C above the room temperature.

(Steam gives up its latent heat as it condenses to water.)

(iv) Stir the water in the calorimeter and record its temperature (*Î¸*$_2$); weigh the calorimeter a third time and record its mass (m_2).

Calculations

Mass of water $m_w = m_1 - m_c$

Mass of condensed steam $m_s = m_2 - m_c$

Fall in temperature of steam = 100 – *Î¸*$_2$

Rise in temperature of water and cal. = *Î¸*$_2$ – *Î¸*$_1$

Heat lost by steam = $m_s l_v + m_s c_w (100 - Î¸_2)$
Heat gained by water = $m_w c_w (Î¸_2 - Î¸_1)$
Heat gained by calorimeter = $m_c c_c (Î¸_2 - Î¸_1)$

Heat lost by steam = Heat gained by water and calorimeter
$m_s l_v + m_s c_w (100 - Î¸_2) = m_w c(Î¸_2 - Î¸_1) + m_c c_c (Î¸_2 - Î¸_1)$

Precautions

1. Only dry steam is allowed to enter the calorimeter. *The steam trap is used to remove condensed water (wet steam) from passing into the calorimeter.*
2. The calorimeter and its content are stirred continuously to ensure even temperature.
3. The calorimeter and its content are cooled below the room temperature and warmed above the room temperature by the same amount.
4. A screen or shield is used to stop the heat from the burner from affecting the experiment.

Evaporation

Revision

When a liquid changes to vapour (gas) at ordinary temperature, it is said to evaporate.

Evaporation is the breaking away of liquid molecules from the surface of the liquid and remaining outside the liquid as vapour.

It occurs at any temperature above the absolute zero without reaching the boiling point of the liquid.

Cooling effect of evaporation

Carry out the following activities and state what you observe:

â€¢ Put some drops of methylated spirit on the back of your hand. What happens to your hand as the methyl spirit evaporates?

â€¢ Choose two thermometers and record their readings, cover the bulb of one of the thermometer with cotton soaked in methyl spirit and the bulb of the second thermometer uncovered.

â€¢ Place the two thermometers under a fan, observe and record the reading of the thermometer after few minutes. What do you observe?

Observations

1. In the first activity, the hand feels cold because the methyl spirit extracts latent heat of vaporisation from it. The removal of heat from the hand makes its temperature to drop.
2. In the second activity, the temperature of the thermometer covered with cotton soaked in methylated spirit falls rapidly. The fall in temperature is caused by the evaporation of the methyl spirit

around the bulb.

We conclude that evaporation causes cooling. Liquids like methyl spirit, ether, petrol, etc., which evaporates with ease at ordinary temperature, are called **volatile liquids.**

Figure 8.7 is a simple demonstration to prove that evaporation of liquids produces cooling.

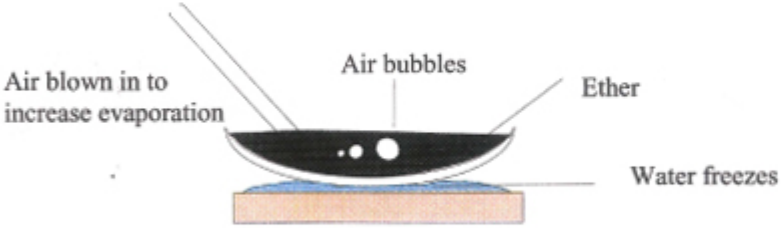


Figure 9.7: Evaporation produces cooling effect

A watch glass with liquid ether is placed on a few drops of water. Dry air is blown through the ether to increase the rate of evaporation. The evaporating ether takes latent heat of vaporisation from the drops of water under the watch glass. The temperature of the water drops falls and some minutes later, the water under the glass freezes. The watch glass sticks to the frozen ice.

Application of evaporation

1. The refrigerator

The refrigerator is a machine which cools food items and other substances kept in them by extracting latent heat from them to vaporise the volatile liquid or **refrigerant**. It consists of the following essential parts:

â€¢ ***A compressor or pump and expansion valve:*** The compressor is used to compress and condense vapour of the refrigerant to liquid while the expansion valve allows for the expansion or evaporation of highly pressurized liquid.

â€¢ ***The cold compartment and the cooling fins:*** The cold compartment gives up latent heat to vaporise the Freon liquid (the refrigerant) while the cooling fins conduct heat away from the condensed Freon liquid.

â€¢ ***The refrigerant:*** The volatile liquid that produces the cooling effect in the refrigerator is called the refrigerant.

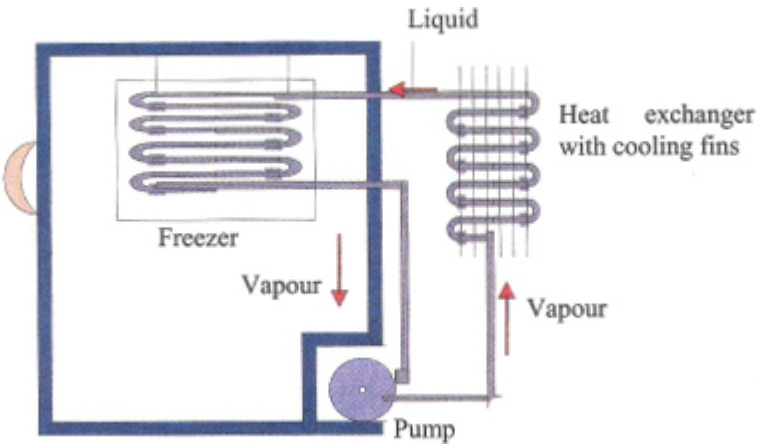


Figure 9.8: The refrigerator

Working of refrigerators

Refrigerants like **Freon, liquid ammonia** and **liquid carbon (IV) oxide** are made to evaporate at low pressure. These liquids obtain their latent heat from the items kept in the cold compartment. The Freon vapour is forced through compressor to the high-pressure pipe where it condenses to liquid at high pressure. The refrigerant gives up its latent heat to the high-pressure pipe and is conducted through the cooling fins to the surroundings. The highly pressurised liquid is forced through the expansion valve into the cold compartment where it evaporates. The process is repeated continuously until the refrigerant is used up.

2. The air conditioner

The air conditioner, like the refrigerator, works on the principle that evaporation produces cooling. Warm air is drawn into the cooling unit where it gives up latent heat to evaporate the refrigerant in the coiled pipe.

Summary

â€¢ Latent heat of fusion is the heat energy needed to change any given mass of a solid to liquid at a constant temperature.

â€¢ Specific latent heat of fusion is the heat energy needed to change 1 kg of a solid to liquid at a constant temperature.

â€¢ Heat absorbed = Mass Ã— Specific latent heat

â€¢ The melting point of a substance is the constant temperature at which it changes state from solid to liquid.

â€¢ Freezing point is the constant temperature at which a substance changes state from liquid to solid.

â€¢ Freezing point of a pure substance is equal to its melting point.

â€¢ The melting point of a pure substance can be changed by adding impurities and changing the pressure on it. Increase in pressure lowers the melting point and freezing point of pure substances.

â€¢ Regelation is the melting of ice and refreezing of water caused by pressure changes. The specific latent heat of vaporization is the heat energy needed to convert 1 kg of a liquid to vapour at constant temperature.

â€¢ The energy given out by 1 kg of steam to condense to water is much greater than the energy absorbed by 1 kg of water to increase its temperature by 100Â°C. This is why steam burn is more dangerous than hot water burn.

â€¢ Evaporation is the breaking away of liquid molecules from the surface of the liquid and remaining outside the liquid as vapour.

â€¢ Evaporation causes cooling. Cooling by evaporation is used in the working of refrigerators and air conditioners.

Practice questions 9b

1. Define *specific latent heat of ice.*

   What is heat energy absorbed to completely melt 500 g of ice at 0Â°C?

   {Specific latent heat of ice = 336000 J kg^{-1}}

2. Define *specific heat capacity* and *specific latent heat of fusion.*

   Calculate the quantity of heat given out to convert 0.3 kg of water at 30Â°C to ice at 0Â°C.

   {Specific heat capacity of water = 4200 J kg^{-1} K^{-1} and specific latent heat of ice = 336000 J kg^{-1}}

3. What do you understand by specific latent heat of fusion?

   An aluminium cup of mass 0.045 kg containing 0.1 kg of water is cooled from 30Â°C to -20Â°C, find the amount of heat energy lost by the aluminium cup and water. {Specific heat capacity of water and ice are 4200 J kg^{-1} K^{-1} and 2100 J kg^{-1} K^{-1} respectively; specific latent heat of ice = 336000 J kg^{-1} specific heat capacity of aluminium = 900 kg^{-1} K^{-1} }

4. Define the *specific latent heat of vaporization of steam.*

   How much heat energy is absorbed to change 2 kg of water at 60Â°C to steam at 100Â°C?

   {Specific latent heat of steam =2260000 J kg^{-1}}

5. Explain what you understand by the statement *specific latent heat of steam* is 2260000 J kg^{-1}?

   Calculate the heat energy needed to convert 250 g of ice at 0Â°C to steam at 100Â°C. {Specific heat capacity of water = 4200 J kg^{-1} K^{-1} and specific latent heat of ice = 336000 J kg^{-1}}

6. (a) Describe an experiment to determine the specific latent heat of ice.

   (b) State two precautions that should be observed to ensure accurate result.

(c) Ice at 0Â°C is added to a copper vessel of mass 80 g containing 120 g of water at 30Â°C. If the maximum steady temperature of the mixture is 10Â°C, find the mass of ice melted.

{Specific heat capacity of water and copper are 4200 J kg^{-1} K^{-1} and 400 J kg^{-1} K^{-1} respectively; specific latent heat of ice = 336000 J kg^{-1}}

7. (a) Describe an experiment to determine the specific latent heat of vaporization of steam;

(b) State two precautions you should observe to obtain an accurate result.

(c) A brass block of mass 280 g at a temperature of 500Â°C is dropped into a vessel of negligible heat capacity containing 300 g of water at 80Â°C; find the mass of water that will boil away.

{Specific heat capacity of water and brass are 4200 J kg^{-1} K^{-1} and 380 J kg^{-1} K^{-1} respectively; specific latent heat of steam = 2260000 J kg^{-1}}

8. Explain the following:

(i) Steam burn is worse than hot water burn.

(ii) Pressure cookers cook food faster and better than other types of cookers.

(iii) One cannot prepare hot tea on Mount Everest without a pressure cooker.

(iv) Two blocks of ice stick together when squeezed.

9. What do you understand by melting point of a substance?

What are the factors that may alter the melting point of ice?

10. (a) Define evaporation and explain why evaporation produces cooling using kinetic theory of matter.

(b) State two factors that may increase the rate of evaporation of liquids.

vapour pressure

OBJECTIVES

At the end of this topic, students should be able to:

- explain the terms vapour pressure and saturation vapour pressure (S.V.P.);
- state the effect of temperature on the saturation vapour pressure;
- explain boiling and determine the boiling points of liquids;
- state the effect of pressure and impurities on boiling point of a liquid;
- distinguish between evaporation and boiling; and
- explain the effects of humidity on personal comfort.

A liquid left exposed will evaporate. Molecules of the liquid with enough energy break away from the liquid and stay outside the liquid as vapour. These free molecules (vapour) are moving constantly and exert pressure on the liquid surface. ***The pressure due to these molecules on the liquid is called* vapour pressure.** The two types of vapour pressure are unsaturated vapour pressure and saturated vapour pressure.

(i) Unsaturated vapour pressure

The vapour which is not in contact with its own liquid in a confined space, is called **unsaturated vapour**. An unsaturated vapour is not in dynamic equilibrium with its own liquid. The rate at which the liquid evaporates is greater than the rate at which it condenses.

The pressure exerted by a vapour which is not in contact with its own liquid in a confined space, is called unsaturated vapour pressure.

(ii) Saturated vapour pressure (S.V.P.)

The vapour which is in contact with its own liquid in a confined space, is called **saturated vapour**. A saturated vapour is in dynamic equilibrium with its own liquid; that is, the number molecules leaving liquid is equal to the number of molecules returning to the liquid. Saturated vapour exerts. Saturated vapour pressure on the liquid called saturated vapour pressure (S.V.P.)

The pressure exerted by a vapour which is in contact with its own liquid in a confined space, is called saturated vapour pressure (S.V.P.).

Measurement of unsaturated and saturated vapour pressures

The vapour pressure of liquid can be studied at room temperature with the help of simple barometers as shown in Figure 8.9. Three barometric tubes P, Q and R are filled with mercury and inverted in a mercury trough B. The barometer Q is used as a control; a small liquid is introduced at the base of barometer P and R using a pipette.

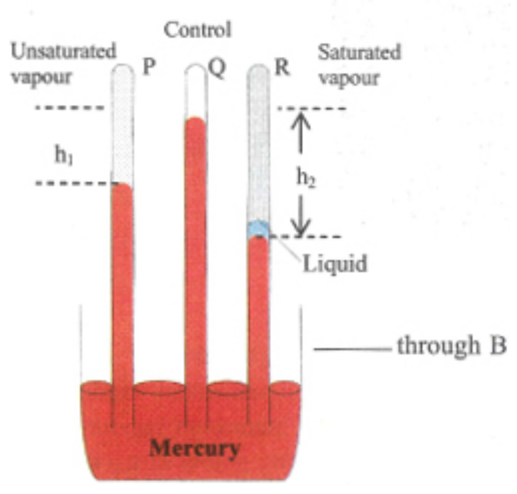


Figure 9.9: Saturated and unsaturated vapour pressures

The liquid rises to the top where it vaporizes and fills the space above the mercury in the confined space. The pressure of the vapour depresses the mercury by h_1 in the barometer P. The depression h_1 is the unsaturated vapour pressure of the liquid.

Addition of liquid in barometer R increases the vapour pressure and the mercury is depressed more. Adding more liquid increases the vapour pressure until the vapour is saturated; a little liquid remains above the mercury. When this happens, the vapour in the space above the liquid is said to be saturated. The saturation vapour pressure (S.V.P.) is the depression h_2 of the barometer R. Saturation vapour pressure (S.V.P.) of a liquid is constant if the temperature of the liquid remains constant.

The effect of temperature on saturation vapour pressure (S.V.P.)

The saturation vapour pressure varies with temperature. At constant temperature, it is constant but increases progressively as the temperature increases. Close to the boiling point of the liquid, the increase in the saturation vapour pressure (S.V.P.) becomes rapid. We can study the variation of SVP using the setup in Figure 8.10.

â€¢ Two simple barometers P and Q are placed in a water bath. Barometer P contains saturated water vapour while barometer Q contains no vapour and is used as a control.

â€¢ The initial temperature and saturation vapour pressure (S.V.P.) h are measured and recorded.

â€¢ Steam is passed into the water bath; the temperature rises gradually. The saturated vapour pressures are measured at different temperatures.

â€¢ The values of S.V.P. are measured at various temperatures and the graph of S.V.P. against temperature shows that the saturation vapour pressure (S.V.P.) increases as the temperature rises.

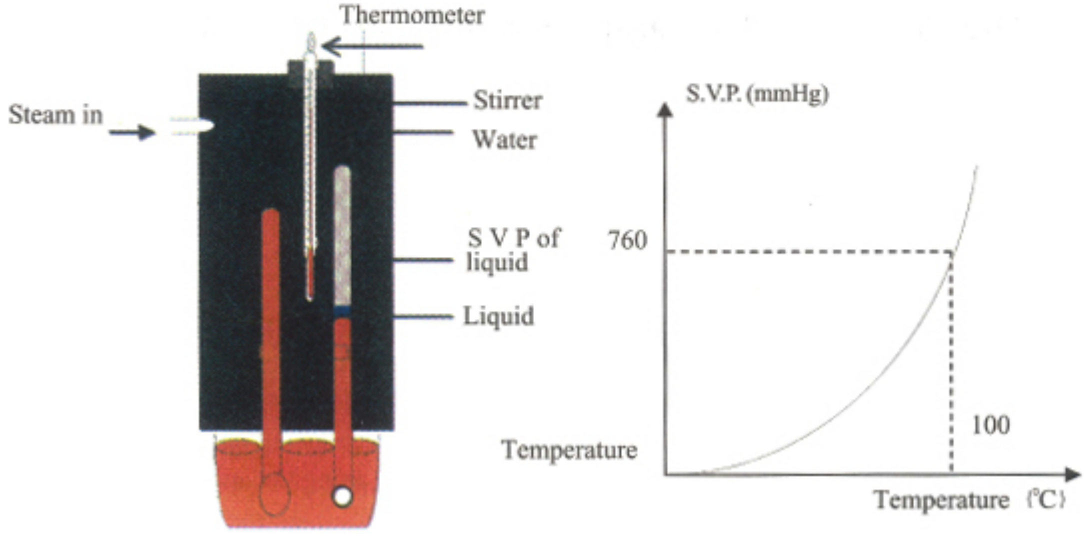


Figure 9.10: Effect of temperature on S.V.P.

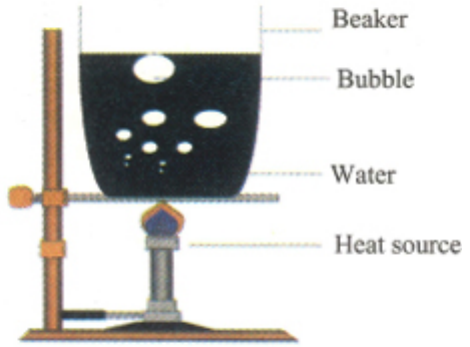


Figure 9.11: Bubbles formation in boiling water

When a liquid is heated in a beaker, bubbles of vapour begin to form at the bottom and rises to the surface. Close to the boiling point of the liquid, the rate of formation of bubbles increases and it forms through out the volume of the liquid. The formation and rising of the bubbles from the bottom to the surface is called **boiling**.

Boiling and saturation vapour pressure

A liquid boils when bubbles are formed throughout the volume of the liquid. The water above the mercury in Figure 9.10 boils when the S.V.P. is 760 mmHg (external pressure). Boiling takes place when the S.V.P. of the liquid is equal to the external pressure.

The pressure inside each bubble at the surface of the liquid is equal to the external pressure on the liquid surface. Inside the liquid, the pressure inside the bubbles is the sum of the external pressure and the pressure due to the weight of the liquid on the bubbles. As the bubbles rise to the surface, their inner pressure decreases, making their size to increase. The bubbles continue to expand until they reach the surface of the liquid where the pressure on them is only the S.V.P. The bubbles burst open because their inner pressure (S.V.P.) is equal to the external pressure. For water, this happens at a standard pressure of 760 mm Hg and a temperature of 100Â°C. The temperature at which a liquid boils is called its **boiling point.**

Boiling point of a liquid is the temperature when the saturation vapour pressure (S.V.P.) of the liquid is equal to the external or atmospheric pressure.

Boiling points of liquids are affected by the **pressure** exerted on its surface and the presence of **impurities.**

(a) Effect of pressure on boiling point

The boiling point of a liquid may vary, depending on the magnitude of the atmospheric pressure at the time of measurement. Increasing the pressure on the liquid surface will increase its boiling point and reducing the pressure on its surface will lower its boiling point.

Water can be forced to boil at a reduced temperature by reducing the pressure on its surface.

We can make water boil at a temperature far below 100Â°C using the apparatus in Figure 9.12.

The procedures are as follows:

â€¢ Water in a flask is boiled to expel all the air above it. The flask is then covered with a tight stopper with a fixed thermometer.

â€¢ When cold water is poured over the flask, the water begins to boil again.

Pouring cold water on the flask makes the steam above the water to condense and a vacuum is formed above the water. The pressure above the water is reduced and the water boils at a lower temperature. Boiling continues until water vapour accumulates above the water surface. If fresh cold water is poured over the flask again, boiling resumes. If the process is repeated, the water continues to boil until its temperature falls to room temperature.

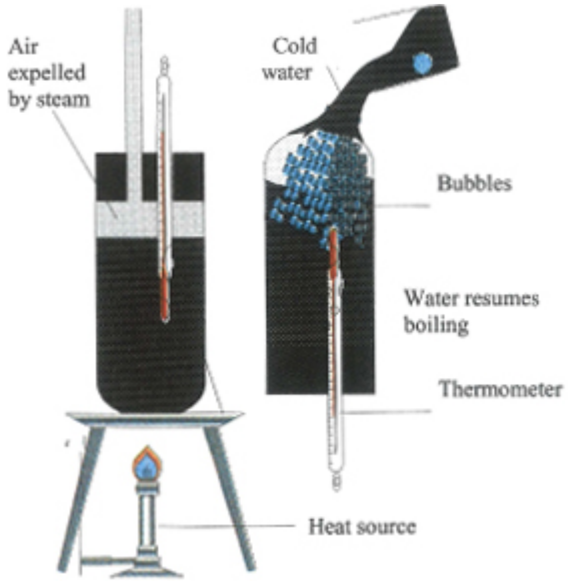


Figure 9.12: Boiling water at a temperature below 100Â°C

We can make water boil without heating it. A vacuum pump is used to pump out air above the water, the water boils when the pressure of vapour above it is less than the S.V.P. of the room temperature.

(b) Effect of impurity on boiling point

Impurities will change the boiling point of a liquid. Salt added to water will increase its boiling point. ***A strong solution of salt will cook food fast than pure water because water boiling at higher temperature contains more energy.*** Some impurities like alcohol, lower the boiling point of water.

Determination of boiling point of small quantity of liquid

Apparatus: A beaker of water, stirrer, thermometer, J-tube, and a source of heat.

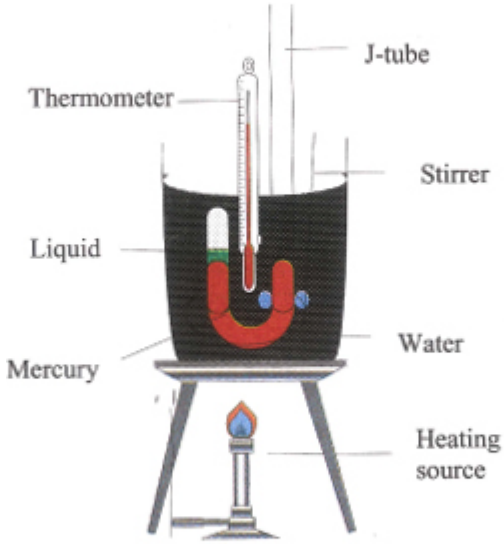


Figure 9.13: Determination of boiling of small quantity of a liquid

Method

The boiling point of a liquid can be found using the fact that a liquid boils when its SVP is equal to the external atmospheric pressure. Some quantity of mercury is poured into a J-tube and air trapped by the mercury is expelled. A small quantity of liquid whose boiling point is to be determined is introduced into the shorter arm of the J-tube until a small quantity remains above the mercury. The J-tube and its content are immersed in a beaker of water and warmed gently. The water is stirred continuously to keep the temperature uniform. As the temperature rises, the water vaporises and depresses the mercury until the levels on both arms of the J-tube are equal. When this happens, the temperature of the thermometer is read and recorded as the boiling point of the liquid. At this temperature, the S.V.P. of the liquid is equal to the external atmospheric pressure. Another measurement of temperature is taken when the levels of mercury in both arms are equal as the beaker and its content are cooling. The average of the two temperatures is the boiling point of the liquid.

Precautions

(i) The water in the beaker is stirred continuously to keep its temperature uniform.

(ii) The readings of the thermometer are taken during the heating and cooling process and the average value recorded as the temperature of the liquid.

(iii) Only a pure liquid should be used since impurities alter the boiling point of a liquid.

(iv) Parallax error should be avoided when taking the reading of the thermometer.

Differences between boiling and evaporation

S/N	Boiling	Evaporation

1.	Boiling takes place throughout the volume of the liquid.	Evaporation takes place at the surface of the liquid only.
2.	Boiling occurs at a definite temperature.	Evaporation occurs at all temperatures.
3.	Wind does not affect the boiling point of a liquid.	Wind increases the rate of evaporation of a liquid.

Table 9.1: Differences between boiling and evaporation

Applications of vapour pressure

â€¢ Boiling at a reduced pressure

Pressure decreases with altitude (height). As one gains height, pressure reduces and it becomes difficult to obtain hot water or cook food. This is because water boils at a temperature less than its boiling point at normal atmospheric pressure; at the top of mountain Everest, the boiling point of water is about 70Â°C. Boiling at reduced pressure and temperature is used in the production of condensed milk, sugar and syrups. A condensed milk is produced by boiling away water from the milk at a reduced temperature to prevent clotting.

â€¢ Pressure cooker

A pressure cooker cooks food faster and better than the normal way of cooking. It is made of a vessel which can be tightly closed and the temperature increased to about 120Â°C at a high pressure. Water boiling at higher temperature contains more energy; therefore, food is cooked faster. Mountain climbers and people living in places with low atmospheric pressure use pressure cookers to boil foods.

Humidity

Our atmosphere is not dry but contains some quantity of water vapour due to constant evaporation from open water sources like oceans, lakes, rivers and evaporation from plants and leaves during photosynthesis. ***Humidity is a measure of wetness of our atmosphere. The exact amount of water vapour in the atmosphere at a given temperature is called absolute humidity.*** The atmosphere becomes saturated when it contains maximum amount of water vapour at a particular temperature. Temperature determines the quantity of water vapour in the atmosphere. At higher temperatures, the atmosphere contains more water vapour compared to water vapour present at low temperatures. The amount of water vapour in kilogram per cubic metre (Kg m^{-3}) needed to saturate the atmosphere varies with temperature as shown in the Table 9.2.

Temperature (Â°C)	Mass of saturated

	vapour (Kg m^{-3})
-10	2.15Ã—10^{-3}
-5	3.25 x10^{-3}
0	4.84Ã—10^{-3}
5	6.76Ã—10^{-3}
10	9.33Ã—10^{-3}
15	12.71Ã—10^{-3}
20	17.12Ã—10^{-3}
25	22.80Ã—10^{-3}
30	30.04Ã—10^{-3}
35	39.18Ã—10^{-3}
40	50.70Ã—10^{-3}

Table 9.2: Variation of temperature and saturated water vapour

Relative humidity

When the mass of water vapour per unit volume present in the atmosphere at a given temperature is compared with the mass of water vapour per unit volume needed to saturate it at the same temperature is called **relative humidity.**

Relative humidity is always expressed in percentage. In terms of saturation vapour pressures, we define relative humidity as:

$$\text{Relative humidity} = \frac{\text{s.v.p. at dew point}}{\text{s.v.p. at room temp}} \times 100\%$$

A relative humidity of 60% means that the air contains 60% of water vapour at the specified temperature.

Worked examples

1. On a certain day, the mass of water vapour per cubic metre of air at 30Â°C is 14.8 g while the mass of water vapour per cubic metre of air required to saturate at the same temperature is 30.04 g. Calculate the relative humidity of the air on this particular day.

Solution

$$\text{Relative humidity} = \frac{m}{M}$$

m = mass of water vapour per unit volume of air at 30Â°C

M = mass of water vapour per unit volume of air at saturation and temperature of 30Â°C

$$\text{Relativehumidity} = \frac{14.8}{30.04} \times 100\% = 49.3\%$$

2. The temperature of certain day in Lagos is 35Â°C and the saturation vapour pressure of air at dew point is 45.28 mm Hg. If the pressure

of air at saturation is 55.13 mm Hg, calculate the relative humidity on this day.

Solution

$$\text{Relative humidity} = \frac{\text{s.v.p. at dew point}}{\text{s.v.p. at room temp}} \times 100\%$$

$$\text{Relative humidity} = \frac{45.28}{55.13} \times 100\% = 82.1\%$$

An environment with high relative humidity like a coastal area, contains a high percentage of water vapour. People living in these areas sweat a lot. The sweat remains on the body since evaporation is low; therefore, the body feels uncomfortable. When the humidity is low, the air is dry and the body may be uncomfortable due to the harsh weather condition as we have during harmmattan or dry season. The dryness of the air encourages evaporation, therefore, sweat evaporates fast and the body loses a large amount of water. The water lost needs to be replaced to keep the body fluid constant.

Hygrometer

The hygrometer measures the relative humidity of an environment. The most commonly used hygrometer is the wet bulb and dry bulb hygrometer. It consists of two thermometers:

â€¢ The dry bulb thermometer is an ordinary thermometer to measure the temperature of the air.

â€¢ The wet bulb thermometer is covered with wet material dipped in water.

Evaporation of water around the wetbulb thermometer makes its temperature lower than the drybulb thermometer. Readings of the two thermometers vary according to the humidity of the place. In a highly humid environment, water evaporates slowly therefore, the readings of both thermometers differ a little. When the surrounding air is dry, the difference in the readings will increase because of the increase in the rate of evaporation of water. We can use the readings of the wet and drytype hygrometer to find the relative humidity of a place.

Dew and dew point

Dew is the visible water droplets formed when the invisible warm water vapour is adequately cooled. This happens if a cold object is placed in a warm environment. Evaporation of water and condensation of water vapour depend on the temperature and the vapour pressure above the water. If the pressure of the vapour is less than its saturation vapour pressure, more water evaporates. When the pressure of the vapour is more than its saturation vapour pressure at a particular temperature, excess water vapour condenses into visible drops of water. The condensation of water vapour to visible drops of water begins at a temperature when the pressure of water vapour is equal to its saturation vapour pressure. The temperature when water vapour begins to form visible drops of water on the cold surface is called the **dew point.**

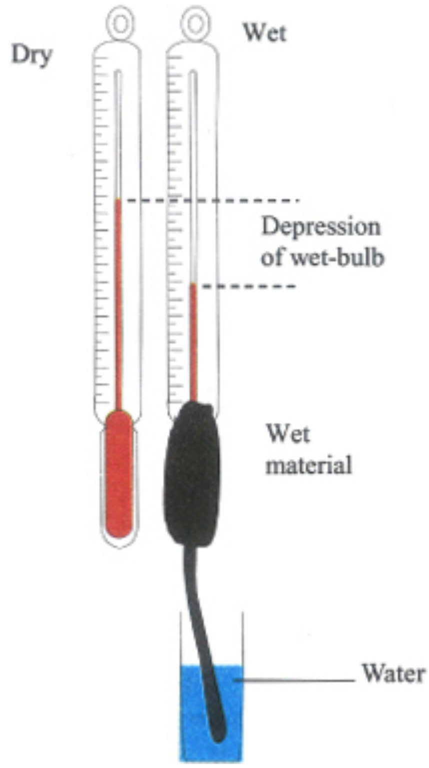


Figure 9.14: Wet – and – dry bulb hygrometer

The dew point is the temperature at which the pressure of the water vapour is equal to the saturation vapour pressure.

When a cold bottle of soft drink or a sachet of water is brought out from the refrigerator, warm water vapour in air around the bottle are cooled below their dew point and condenses into visible drops of water on the soft drink bottle or the sachet of water.

Mist, fog and clouds

Mist occurs in wet air with high relative humidity above 75% when water vapour in the air is cooled below its dew point. Visible tiny drops of water are condensed from the water vapour. These tiny drops of water float about like cloud near the ground. Mist limits visibility to about 1000 m or less.

Fog is formed when water vapour in the air is cooled down to its dew point. Water vapour condenses as visible drops of water on suspended dust and smoke particles forming dense cloud close to the ground. Fog is more serious than a mist as visibility is reduced to less than 200m.

The atmosphere high above is cooler than the ones below. Water vapour rising above the ground level cools as it expands. At a certain height, the temperature of water vapour falls below its dew point and condenses into clouds.

Summary

â€¢ **Vapour pressure** is the pressure exerted by the molecules on its own liquid.

â€¢ **Unsaturated vapour pressure** is the pressure exerted by a vapour which is **not** in contact with its own liquid in a confined space.

â€¢ **Saturation vapour pressure** (S.V.P.) is the pressure exerted by a vapour which is in contact with its own liquid in a confined space.

â€¢ The saturation vapour pressure (S.V.P.) of a liquid is constant at constant temperature.

â€¢ Saturation vapour pressure of a liquid increases with temperature.

â€¢ **Boiling** is the formation and rising of the bubbles from the bottom to the surface of a liquid. This happens at a constant temperature called boiling point.

â€¢ **Boiling point of a liquid** is the temperature when the saturated vapour pressure (S.V.P.) of the liquid is equal to the external atmospheric pressure. The boiling point of water at normal atmospheric pressure is 100Â°C.

â€¢ The boiling points of liquids are affected by the **pressure** exerted on its surface and the presence of **impurities.**

â€¢ Boiling at reduced pressure and temperature is used in the production of condensed milk, sugar and syrups.

â€¢ **Humidity** is a measure of wetness of our atmosphere.

â€¢ **Relative humidity** is the ratio mass of water vapour per unit volume present in the atmosphere at a given temperature to the mass of water vapour per unit volume needed to saturate it at the same temperature.

• $\text{Relative humidity} = \dfrac{\text{s.v.p. at dew point}}{\text{s.v.p. at room temp}} \times 100\,\%$

â€¢ **Hygrometer** is used to measure the relative humidity of a place.

â€¢ **Dew point** is the temperature when water vapour in the atmosphere begins to condense into visible drops of water on a cold surface.

â€¢ **Mist** is cloud of tiny drops of water formed near the ground.

â€¢ **Fog** is a dense cloud of water drops formed on suspended dust and smoke particles when water vapour cools to its dew point near the ground.

â€¢ **Clouds** are formed up in the sky as water vapour rises up, expands and cools down to its dew point.

Practice questions 9c

1. What do you understand by the terms *saturated* and *unsaturated vapour?*
2. State the differences between saturated vapour and unsaturated vapour.
3. (a) Define the saturated vapour pressure of a liquid at a particular temperature.
   (b) What is the effect of temperature on the saturated vapour pressure of a liquid?
   (c) Describe an experiment to show the effect of temperature on the saturated vapour pressure of a liquid.
4. Explain the meaning of the statement the saturation vapour pressure of a liquid is 15 cm Hg.
5. (a) Define the boiling point of a liquid.
   (b) State the differences between boiling and evaporation.
   (c) State two factors which affect both boiling and evaporation of a liquid and describe how boiling and evaporation depend on the factors.
6. (a) What do you understand by the boiling point of liquid?
   (b) How is the boiling point of water affected by
      (i) increase in the atmospheric pressure
      (ii) addition of salt?
7. (a) Define relative humidity and dew point.
   (b) The relative humidity of a town is 65%, explain the meaning of the statement.
   (c) The relative humidity of a room is 65% when the air inside the room contains 14.82 g of water vapour per unit volume at a temperature of 25Â°C. What is mass of water vapour per unit volume that must be added to the room to saturate it at 25Â°C?
8. Explain why the atmosphere contains some amount of water vapour.
9. Explain how the following are formed:
   (i) Mist and fog
   (ii) Dew and cloud

Past questions

1. A metal ball of mass 1.5 kg is heated from 27Â°C to 47Â°C in 4 minutes by a boiler rated 75 W. Calculate the specific heat capacity of the metal. {Neglect heat losses}

   A. 600 J kg^{-1} K^{-1}
   B. 250 J kg^{-1} K^{-1}
   C. 200 J kg^{-1} K^{-1}
   D. 100 J kg^{-1} K^{-1}

   WASSCE

2. The heat capacity of calorimeter is the amount of energy required to

A. change the temperature of 1 kg of the calorimeter by 1 k.

B. change 1 kg mass of the calorimeter to liquid at the same temperature.

C. change the temperature of the calorimeter by 1 k.

D. melt the calorimeter into liquid at a constant temperature. **WASSCE**

3. Which of the following is not used to determine the heat content of a body?

A. Mass of the body.

B. Volume of the body.

C. Specific heat capacity of the body.

D. Temperature of the body. **WASSCE**

4. Calculate the quantity of heat required to completely convert 20 g of ice at 0Â°C to water at the same temperature. {Specific latent heat of fusion of ice = 336 J g^{-1}}

A. 8.06 kJ

B. 7.06 kJ

C. 6.72 kJ

D. 5.38 kJ **WASSCE**

5. Water of mass 120 g at 50Â°C is added to 200 g of water at 10Â°C and the mixture is well stirred. Calculate the temperature of the mixture.

{Neglect heat losses to the surrounding}

A. 60Â°C

B. 40Â°C

C. 25Â°C

D. 10Â°C **WASSCE**

6. A waterfall is 630 m high. What is the change in temperature of a quantity of water that falls from the top to the bottom of the waterfall? {Neglect heat lost to the surroundings, take g as 10 ms^{-2} and specific heat capacity of water as 4200 J kg^{-1} K^{-1}}

A. 0.15Â°C

B. 1.50Â°C

C. 15.00Â°C

D. 21.00Â°C

E. 150.00Â°C **NECO**

7. When 30 g of water at 30Â°C is mixed with 12 g of hot water, the resulting temperature of the mixture is 40Â°C. Calculate the temperature of the hot water, assuming no loss of heat to the

surroundings.

A. 35Â°C

B. 44Â°C

C. 55Â°C

D. 65Â°C **WASSCE**

8. How long will it take to heat 3 kg of water from 28Â°C to 88Â°C using an electric kettle, which taps 6A from a 210 V supply? {Specific heat capacity of water is = 4200 J kg^{-1} K^{-1}}

A. 5.6 minutes

B. 9.6 minutes

C. 10.0 minutes

D. 19.3 minutes **WASSCE**

9. The quantity of heat energy needed to freeze one kilogram of milk at its freezing point is known as

A. heat capacity.

B. latent heat of fusion.

C. specific latent heat of fusion.

D. specific heat capacity. **WASSCE**

10. All the heat generated by a current of 2 A passing through a 6 Î© resistor for 25 s is used to evaporate 5 g of a liquid at its boiling point. What is the specific latent heat of the liquid?

A. 60 J g^{-1}

B. 120 J g^{-1}

C. 300 J g^{-1}

D. 360 J g^{-1} **WASSCE**

11. The amount of heat given out or absorbed when a substance changes its state at constant temperature is known

A. latent heat

B. heat capacity.

C. specific latent heat.

D. specific heat capacity. **WASSCE**

12. A block of ice of mass 10 kg at 0Â°C absorbs energy from its surroundings and changes to water at the same temperature. The heat absorbed is referred to as

A. heat capacity.

B. latent heat.

C. specific heat.

D. specific heat capacity.

E. specific latent heat. **NECO**

13. How much heat is required to convert 5.0 g of ice at 0Â°C to water at boiling point? {Specific latent heat of ice = 336 J g^{-1}; specific heat capacity of water = 4.2 J g^{-1}.}

A. 420 J

B. 1680 J

C. 1701 J

D. 2100 J

E. 3780 J **NECO**

14. Calculate the energy required to vaporise 50 g of water initially at 80Â°C. {Specific heat capacity of water = 4.2 J g^{-1} K^{-1}, specific latent heat of vaporisation of water = 2260 J g^{-1}}

A. 113 000 J

B. 117200 J

C. 234 400 J

D. 420 000 J **WASSCE**

15. Which of the following statements about latent heat of vaporisation is correct? It

A. weakens the adhesive forces between molecules of a liquid and its container.

B. breaks completely the force of attraction between the molecules of a liquid.

C. adds to the heat of a liquid.

D. increase the cohesive forces between liquid molecules. **WASSCE**

16. The statement that evaporation produces cooling can be explained on the basis of kinetic theory by the following statements:

I Some molecules of the liquid have kinetic energy greater than the average.

II The faster-moving molecules of the liquid escape

III The temperature of the remaining liquid falls

IV The average kinetic energy of the remaining molecules is reduced.

Which of the following is the correct sequence of these statements?

A. I, II, IV and III

B. I, II, III and IV

C. II, III, IV and I

D. II, I, IV and III

17. When the saturated vapour pressure of a liquid is equal to the external atmospheric pressure, the liquid

A. boils.

B. expands.

C. evaporates.

D. freezes. **WASSCE**

18. Which of the following physical quantities affects the saturated vapour pressure of a liquid?

A. Temperature

B. Volume

C. Mass

D. Density **WASSCE**

19. Water in a pressure cooker boils at a temperature higher than 100Â°C. This is because

A. heat supplied is increased.

B. rate of heating is reduced.

C. cooker maintains a higher pressure.

D. cooker is used at high altitude. **WASSCE**

20. Water in an open container boils at a lower temperature when heated at the top of a mountain than at sea-level because at the top of a mountain

A. pressure is increased.

B. pressure is reduced.

C. the rays of the sun add more heat to thewater.

D. the saturation vapour pressure of water is higher than at sea-level.

E. The temperature is lower than at sea-level. **NECO**

21. Which change(s) can alter the boiling point of water?

I. Increasing the volume of water.

II. Increasing the external pressure.

III. Increasing the quantity of impurities in the water.

A. I only

B. II only

C. I and II only

D. II and III only

E. I, II and III **NECO**

22. The temperature at which the saturate vapour pressure of a liquid is equal to the external atmospheric pressure is known as its

A. dew point.

B. boiling point.

C. lower fixed point.

D. triple point. **WASSCE**

23. Humidity is used to describe the amount of

A. air in water.

B. cloud available in the atmosphere.

C. air in equal volumes of cloud.

D. water vapour in the atmosphere. **WASSCE**

24. The mass of water vapour in a given volume of air is 0.05 g at 20Â°C, while the mass of water vapour required to saturate it at the

same temperature is 0.15 g. Calculate the relative humidity of the air.

A. 3.33%

B. 5.55%

C. 33.33%

D. 55.55% **WASSCE**

25. A hygrometer is an instrument used to measure

A. dew point.

B. temperature.

C. relative density.

D. relative humidity.

E. vapour pressure. **WAEC**

26. Cloud formations is the direct result of

A. precipitation.

B. vaporisation.

C. condensation.

D. sublimation.

E. fusion. **WAEC**

27. The phenomenon whereby the water droplets in the atmosphere combine with dust particles in the air to reduce visibility is

A. hail.

B. cloud.

C. fog.

D. mist. **JAMB**

28.

	Day 1	**Day 2**	**Day 3**
Dry	30Â°C	29Â°C	25Â°C
Wet	22Â°C	22Â°C	21Â°C

The readings below are for three consecutive days from a wet and dry bulb hygrometer. It can be concluded that the relative humidity for the three days

A. increased steadily

B. remained unchanged

C. was least on Day 1

D. decreased steadily

JAMB

29. Explain the meaning of the statement, *the specific heat capacity of copper is 400* $J\ kg^{-1}K^{-1}$. The temperature of a metal block of mass 100 g is raised to 100Â°C. The block is quickly and gently

transferred into 200 g of water at 30Â°C and the mixture well stirred. If the final temperature of the mixture is 45Â°C, calculate the specific heat capacity of the material of the block. {Assume that no heat is lost to the surrounding and the container has negligible heat capacity. Specific heat capacity of water is 4200 J kg^{-1} K^{-1}.}

WASSCE

(b) With the aid of a labelled diagram, describe an experiment to determine the specific heat capacity of copper using a copper ball.

State two precautions necessary to obtain accurate results.

(c) A piece of copper block of mass 24 g at 230Â°C is placed in a copper calorimeter of mass 60 g containing 54 g of water at 31Â°C. Assuming heat losses are negligible; calculate the final steady temperature of the mixture. {Specific heat capacity of water is 4200 J kg^{-1} K^{-1}; Specific heat capacity of copper is 400 Jkg^{-1} K^{-1}}

WASSCE

31. Define *specific latent heat of vaporisation.*

An electric heater immersed in water of mass m, raised the temperature of the water from 40Â°C to 100Â°C in 5.00 minutes. After another 11.25 minutes, one quarter of the water had being converted to steam. Calculate the specific latent heat of vaporisation of water. {Specific heat capacity of water = 4200 J kg^{-1} K^{-1}}

WASSCE

32. Using kinetic theory of matter, explain why

(i) evaporation causes cooling;

(ii) boiling water changes to steam without change in temperature.

WASSCE

33. (a) Define the boiling point of a substance.

(b) What is the effect of an increase in pressure on the boiling point of water?

(c) Describe, with the aid of a labelled diagram, an experiment to determine the boiling point of a small quantity of a liquid.

NECO

34. An electric heater rated 1kw immersed in some water raises the temperature of the water from 40Â°C to 100Â°C in 6 minutes. After another 25 minutes, it is noticed that half of the water has boiled away. Neglecting heat losses to the surrounding, calculate the specific latent heat of vaporisation of water.

WASSCE

35. (a) Define the boiling point of a liquid.

(b) Describe, with the aid of a labelled diagram, an experiment to determine the boiling point of a small quantity of a liquid.

(c) State two factors that may affect the boiling point of a liquid.

(d) Using the kinetic theory of matter, explain why pure water changes state to steam at s.t.p. without change in temperature, although heat is being supplied to the water.

WAEC

36. (a) Explain what is meant by the following statement: the specific latent heat of fusion of ice is 3.4 Ã— 10^5 J kg^{-1}.

(b) Describe an experiment to determine the specific latent heat of fusion of ice. State two precautions necessary to obtain accurate results.

(c) Using the kinetic theory of matter, explain why ice changes state to water at 0Â°C without change any in temperature.

WAEC

37. (a) Define the boiling point of a liquid.

(b) Describe an experiment to determine the boiling point of a small quantity of a liquid.

(c) A piece of copper of mass 300 g at a temperature of 950Â°C is quickly transferred to a vessel of negligible thermal capacity containing 250 g of water at 25Â°C. If the final steady temperature of the mixture is 100Â°C, calculate the mass of water that will boil away. {Specific heat capacity of copper and water are 400 J kg^{-1} K^{-1} and 4200 J kg^{-1} K^{-1} respectively; Specific latent heat of vaporisation of steam is 2.26 Ã— 10^6 kg^{-1}.}

WAEC

38. Explain *saturated vapour pressure.*

A heating coil of resistance 20 Î© connected to a 220 V source is used to boil a certain quantity of water in a container of heat capacity 100 J kg^{-1} for 2 minutes. If the initial temperature of the water is 40Â°C, calculate the mass of the water in the container. {Specific heat capacity of water = 4.2 Ã— 10^3 J kg^{-1} K^{-1}, assume boiling point of water = 100Â°C.}

WASSCE

39. (a) State two differences between boiling and evaporation.

(b) Use the kinetic theory of matter to explain why evaporation causes cooling.

(c) State two factors each which affect the:

(i) boiling point of a liquid;

(ii) rate of evaporation of a liquid.

(d) Define dew point and relative humidity. On a certain day, the temperature and dew point of a sample of air were found to be 16.0Â°C and 10.0Â°C respectively. From tables, the corresponding saturation vapour pressure was obtained as 13.5 mmHg and 9.2 mm Hg respectively. Calculate the relative humidity of the sample.

WASSCE

40. (a) Explain the terms:
    (i) relative humidity
    (ii) dew point.
  (b) Describe the experiment to show that evaporation causes cooling. Mention two factors on which the evaporation of a liquid depends, indicating the effect of each factor on the rate of evaporation.
  (c) The mass of water vapour in a given volume of air at 20Â°C is 0.05g. The air requires 0.15g of water vapour to saturate it at the same temperature. Calculate the relative humidity of the air.

WASSCE

41. (a) Explain *specific latent heat.*
  (b) (i) Describe how the specific latent heat of fusion of ice can be determined by the method of mixture.
    (ii) State two precautions to be taken to ensure accurate results.
  (c) Steam, at 100Â°C, is passed into a container, of negligible heat capacity, containing 20 g of ice and 100 g of water at 0Â°C, until the ice is completely melted. Determine the total mass of water in the container.

[Specific latent heat of steam = 2.3 **Ã—** 10^3 J g^{-1}, Specific latent heat of ice = 3.4 **Ã—** 10^2 J g^{-1}, Specific heat capacity of water = 4200 J kg^{-1} K^{-1}.]

WASSCE