

Module 3 Applications of Thermal Properties of Matter

This module is designed to help you to:

- define the specific heat of a gas at constant pressure;
- define the specific heat of a gas at constant volume;
- apply the principle of calorimetry;
- explain convection as the mode of transfer of heat in fluids;
- apply the concept of evaporation, melting, freezing and latent heat of vaporization in daily life;
- discuss the effect of pressure on the freezing point of water;
- relate thermal physics to practical situations in daily life.

Content

11.3.1 Introduction

11.3.2 Specific heat

11.3.3 Specific heats of a gas

11.3.4 Calorimetry

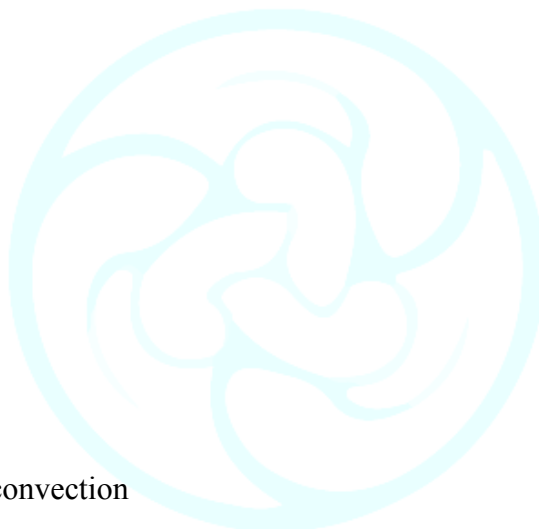
11.3.5 Convection of heat

11.3.5.1 Natural convection

11.3.5.2 Artificial or forced convection

11.3.6 Some practical applications of thermal physics

11.3.7 Summary



11.3.1 Introduction

Heat, a form of energy, plays a vital role in our life. Exchange of heat between two systems results in a change in the temperature or state. However, if an equal amount of heat is added to an equal mass of different substances, the resulting rise in temperature is not the same. Coastal areas have moderate weather conditions whereas weather conditions in some other areas such as polar regions and deserts are extreme. The wind is seen to reverse its direction during day and night in the coastal regions. In general the phenomenon involved is quite complex. However, we will try to understand the methods of heat transfer and its consequences in brief.

11.3.2 Specific heat

Equal amounts of heat added to equal masses of different substances, do not produce the same change in temperature. The change in temperature depends on the nature of the material. For every substance there is a characteristic value for the amount of heat absorbed (or rejected) to change the temperature of its unit mass by one degree. This quantity is referred to as the specific heat or specific heat capacity, s , of the substance. Let ΔQ be the change in the heat content of a body of mass m resulting in a change ΔT in its temperature. The specific heat of the material of the body, by definition, is

$$s = \frac{1}{m} \frac{\Delta Q}{\Delta T} \quad (11.3.1)$$

11.3.3 Specific heats of a gas

Eq(11.3.1) gives a well defined value of s for solids and liquids. However this is not so in case of gases as discussed below.

Let us see what happens when a small amount of heat ΔQ is absorbed or rejected in different situations by a gas.

Case I: Let a certain mass m of a gas, thermally insulated from the surroundings, be suddenly compressed. It will be heated up showing that there is an increase in its temperature, even when no heat is added to the gas from outside that is $\Delta Q = 0$, then $s = 0$

Case II: Let the same mass m of a gas be allowed to undergo expansion slowly in a container made up of a perfect conductor of heat. The gas will now be cooled down. Suppose we carry out the expansion of gas slowly so that its temperature is kept constant by supplying it with an amount of heat ΔQ . From the above equation, we get,

$$s = \frac{\Delta Q}{m \Delta T} = \infty. \quad \text{as } \Delta T \text{ is zero.}$$

Thus, depending upon the external conditions or the process under which heat transfer takes place, the specific heat of a gas may vary from 0 to ∞ . However, while dealing with the gases, we like to have their specific heats under some particular conditions that will give a non-infinite and not-zero value. These conditions should however, be achievable. Keeping the conditions in mind to change the temperature of an enclosed gas, heat energy can be conveniently supplied at

(i) constant volume

(ii) constant pressure.

Thus, there are two possible standard specific heats for an enclosed gas namely,

c_V = specific heat at constant volume and

c_P = specific heat at constant pressure

Thus, c_V is defined as the amount of heat required to raise the temperature of 1 kg of a gas through 1 K when its volume is kept constant.

c_P is defined as the amount of heat required to raise the temperature of 1 kg of a gas through 1 K when its pressure is kept constant.

For one mole(mass M) of the gas, the molar specific heats are

$$C_P = M c_P$$

$$C_V = M c_V$$

C_V and C_P are respectively the molar specific heats of gases at constant volume and at constant pressure.

For gases, we always have, $C_P > C_V$.

For a gas heated at constant volume, the heat supplied is utilised only in increasing the temperature. When the gas is heated at constant pressure, a part of the heat supplied is also used in doing work against external

pressure. Therefore, to raise the temperature of a unit mass of a gas through 1 K, more heat is required when the gas is heated at constant pressure than when it is heated at constant volume. Hence C_p is greater than C_v .



Let Us Reflect

Q.11.3.1 C_p and C_v are the molar specific heats of a gas at constant pressure and constant volume respectively. Which of the following is correct?

- (A) $C_p = C_v$
- (B) $C_p < C_v$
- (C) $C_p > C_v$
- (D) The relation between C_p and C_v depends on the nature of the gas.

Q.11.3.2 Q_1 is heat required to raise the temperature of a unit mass of an ideal gas by 1°C at constant volume.

Q_2 is heat required to raise the temperature of the same mass of the gas by 4°C at constant pressure. The ratio

$\frac{Q_2}{Q_1}$ is

- (A) < 4
- (B) $= 4$
- (C) > 4
- (D) lies between 3 and 4.



Answers

A.11.3.1 (C)

A.11.3.2 (C)

11.3.4 Calorimetry

Calorimetry means measurement of heat. When a body at higher temperature is brought in contact with another body at lower temperature, the heat lost by the hot body is equal to the heat gained by the colder body, provided no heat is allowed to escape to the surroundings. Moreover, there should not be any chemical reaction occurring which may lead to absorption or evolution of heat. A device in which heat measurements can be made is called a calorimeter.

Suppose a body A of mass m_1 , specific heat s_1 at temperature T_1 is placed in thermal contact with another body B of mass m_2 , specific heat s_2 at temperature T_2 . ($T_1 > T_2$.)

Let T be the equilibrium temperature (the final constant temperature of A and B).

$$\text{Heat lost by A, } Q_1 = m_1 s_1 (T_1 - T) = m_1 s_1 \Delta T$$

$$\text{Heat gained by B, } Q_2 = m_2 s_2 (T - T_2) = m_2 s_2 \Delta T$$

As no heat is lost to the surroundings, we have

Amount of heat lost by hot body A = Amount of heat gained by cold body B

$$Q_1 = Q_2$$

$$\text{Or, } m_1 s_1 (T_1 - T) = m_2 s_2 (T - T_2)$$

$$\text{Or, } T = \frac{m_1 s_1 T_1 + m_2 s_2 T_2}{m_1 s_1 + m_2 s_2} \quad (11.3.2)$$

Alternately in terms of heat capacities, we have,

$$T = \frac{C_1 T_1 + C_2 T_2}{C_1 + C_2} = \frac{Q_1 + Q_2}{C_1 + C_2} \quad (11.3.3)$$

where $C_1 (=m_1 s_1)$ and $C_2 (=m_2 s_2)$ are the heat capacities (also called thermal capacities) of the two bodies.



Let Us Reflect

Q.11.3.3 100 g of water in a calorimeter at 70°C is mixed with 50 g of a liquid at 14°C . The equilibrium temperature of the mixture is [specific heats of water and liquid are $1\text{ cal g}^{-1}\text{ }^{\circ}\text{C}^{-1}$ and $0.8\text{ cal g}^{-1}\text{ }^{\circ}\text{C}^{-1}$ respectively]

- (A) 48°C
- (B) 51.5°C
- (C) 54°C
- (D) 60°C

Q.11.3.4 A solid of mass 50 g heated to 90°C is poured into a calorimeter containing 75 g of water at 10°C . The equilibrium temperature of the system is 30°C . The specific heat of solid is

- (A) $0.4\text{ cal g}^{-1}\text{ }^{\circ}\text{C}^{-1}$
- (B) $0.45\text{ cal g}^{-1}\text{ }^{\circ}\text{C}^{-1}$
- (C) $0.5\text{ cal g}^{-1}\text{ }^{\circ}\text{C}^{-1}$
- (D) $0.55\text{ cal g}^{-1}\text{ }^{\circ}\text{C}^{-1}$



Answers

A.11.3.3 (C)

A.11.3.4 (C)

11.3.5 Convection of heat

Convection is a mechanism of heat transfer by actual movement of the particles of the medium. In general, liquids and gases are heated by this process.

Convection can be of two types -

- (i) natural
- (ii) artificial or forced.

11.3.5.1 Natural convection

Here the convection currents are generated by the density difference arising from the temperature gradient in the fluid. Following activity shows natural convection.

Activity 11.3.1

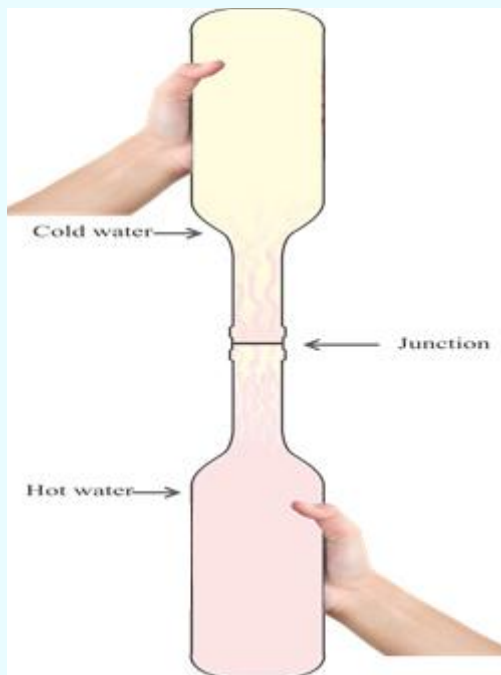


Fig.11.3.1: *Thermal convection*

- Take two commonly available mineral water bottles (say 300 ml each).

- Fill up one with warm water (temperature about 45°C to 50°C). Add a few ink/colour drops in it.
- Fill up the other bottle up to the brim with cold water (about 10°C). Close the mouth of the bottle with the thumb and carefully place it upside down over the mouth of the other bottle (Fig.11.3.1).
- Remove the thumb such that the mouth of the cold water bottle is on top of the other.
- Ensure that not much water goes out of the bottles.
- Observe carefully and record the observations.

After a minute or so, the water current is set up resulting in a gradual change in the colour of the cold water. A closer look shows that convection currents have been set up. The warmer water being lighter, the particles from the lower bottle can be seen to move up. Simultaneously, the denser colder water particles from the upper bottle move down. The convection currents result in raising the temperature of the water in the upper bottle.

Watch water with a few tea leaves being heated in a utensil on a gas stove. The temperature at the bottom is higher. This results in a decrease in density near the bottom. So the hot particles rise up from the bottom and are replaced by the colder particles moving downwards from the sides. The convection currents show how the colder particles come to the source (the flame), receive heat and move up.

The rise of soot from the tip of a burning candle is another example of this mode of heat transfer.

11.3.5.2 Artificial or forced convection

Forced convection is the mechanism of heat transfer through a fluid in the presence of a bulk fluid motion forced by some external agent like a fan, pump or a suction device.

For example, heat circulation in a room is maintained by forcing the air to move past an electrically heated rod in a blower. In this case, transfer of heat is achieved by means of convection forced by a fan. An exhaust fan helps to transfer heat from the interior of a room by generating motion of the air molecules. Central air conditioning, cooling of an automobile engine, hair dryers and hand dryers in public conveniences are some other examples. It should be noted that both natural and forced convection can coexist.

11.3.6 Some practical applications of thermal physics

A large number of natural phenomena occur because of the thermal behaviour of different materials. Change of state of substances is very important in this regard. A number of applications in daily life are based on the change of state, high specific heat of water, anomalous expansion of water, etc.

Pressure cooker

The boiling point of a liquid increases with increase in pressure. This principle is used in steam engines, boilers and pressure cookers etc. The steam produced inside the cooker is not allowed to escape. The pressure inside the cooker becomes higher than the atmospheric pressure. The water in the cooker attains a temperature higher than normal boiling point. This ensures faster cooking and fuel efficiency.

Examples and applications of latent heat of vaporization of water

- (i) Steam at 100°C causes more severe burns than water at 100°C due to the large value of its latent heat.
- (ii). High latent heat of steam is used for heating coffee. The steam condensed into water releases a large amount of heat(latent heat).

Examples and applications of cooling caused by evaporation

- (i) In hot weather, we perspire. Water from our body comes out of the fine pores of the skin. Water evaporates and takes up the heat of vaporization from the body. Due to this reason, we have a cooling sensation.
- (ii) A person wearing wet clothes feels cold because water evaporates by taking the latent heat of vaporization from the body.
- (iii) Water in an earthen pot remains cool in summer. Water comes out of the pores of the vessel and evaporates by taking latent heat from the remaining water. Therefore water remains cool in the earthen pot.
- (iv) Dogs keep their tongues out in summer. Water evaporates from the tongue and keeps them cool.
- (v) Wet khus–khus mats are commonly used in summer. Water evaporates and takes heat from the air in the room, lowering the temperature inside the room.
- (vi) Cold pads soaked in ice cold water are used to lower the body temperature during high fever. Water evaporates, absorbing heat from the body.

- (vii) Hot liquids are poured in a flat plate to increase the surface area. The rate of evaporation increases resulting in faster cooling.

Examples and applications of melting and freezing

- (i) The aquatic animals survive under the frozen water in ponds, lakes and oceans in regions having severe winters. The ice formed floats on the surface due to lower density. The ice layer on top prevents heat from escaping due to its poor conduction property. Water at 4°C has the highest density. This helps the aquatic animals to survive at the bottom of the lake/ocean/pond in winters.
- (ii) The rocks in the mountains crack in frosty weather. When the water freezes into ice, it expands leading to an increase in volume. This widens the cracks in rocks and may break them.
- (iii) Alloys which expand on freezing (or solidification) are used for better casting (making moulds). The alloy in the molten form is poured into the cast, when it freezes, it expands in volume and a sharp casting is obtained.

Examples and applications of high latent heat of ice

- (i) Since latent heat of ice is large, the water in ponds or lakes freezes slowly and the fish and other aquatic animals can survive.
- (ii) Due to high latent heat, snow melts slowly and supplies water to the rivers throughout the year. Had the latent heat been low, the snow would melt faster, causing floods in rivers.
- (iii) When water freezes to form ice, an increase in volume. The bursting of water pipes in regions of cold climate is due to the expansion of water on freezing.

Examples and applications of the effect of pressure on freezing point of ice



Fig 11.3.2: *Ice Lolly*

Ice skating is possible on snow due to the formation of a thin layer of water below the skates. The water droplets formed due to the increase in pressure acting as ball bearings.

A phenomenon termed regelation, plays a role in this case. **Regelation** is the phenomenon in which the ice melts to water below 0°C at pressures exceeding atmospheric pressure. It refreezes back to ice on the removal of the excess pressure. Another interesting application is making ice lollies (gola, Fig 11.3.2). The shavings of ice are pressed together to form an ice lolly. The pressure exerted melts the ice. When pressure is released it freezes back to ice quickly.



11.3.7 Summary

- Specific heat of a gas at constant pressure is the quantity of heat required to raise the temperature of a unit mass of the gas by one unit at constant pressure.
- Specific heat of a gas at constant volume is the quantity of heat required to raise the temperature of a unit mass of the gas by one unit at constant volume.
- Calorimetry relates to measurements in thermal physics.
- In fluids, the transfer of heat takes place through convection in which the fluid particles physically move through its entire volume due to the density gradient arising due to temperature difference within the liquid.
- In a pressure cooker the boiling point of a liquid increases due to an increase in pressure. This makes the water inside the pressure cooker attain a higher temperature.



Development Team

R.Joshi, Former Associate Professor, DESM, NCERT, New Delhi

Review Team

C.K. Ghosh, Former Director, NCIDE, IGNOU, New Delhi.

K.L.Chopra, Former Associate Professor, Hans Raj College, Delhi University, Delhi

Anuradha Rajesh, Physics Teacher, Shaheed Rajpal DAV Public School, Delhi

Ish K.Gogia, Former PGT, KVS, New Delhi

Member- Coordinator

Shashi Prabha, Professor, CIET, NCERT, New Delhi

Technical support

Riya Rani, JPF, CIET, NCERT, New Delhi

Bhawana Bhatt, Technical Content Developer, CIET, NCERT, New Delhi

Rajat Kumar, Graphic Designer, CIET, NCERT, New Delhi

