Thermal properties of matter

- Heat is the form of energy transferred between two (or more) systems or a system and its surroundings by virtue of temperature difference. The SI unit of heat energy transferred is expressed in joule (J) while SI unit of temperature is kelvin (K), and °C is a commonly used unit of temperature.
- A relationship for converting between the twoscales may be obtained from a graph ofFahrenheit temperature (t_F) versus Celsius temperature (t_C) in a straight line ,whose equation is

  $(t_F - 32)/180 = t_C/100$
- Ideal gas equation:

  $PV = \mu RT$

  where, μ is the number of moles in the sample of gas and R is called universal gas constant:

  $R = 8.31\ J\ mol^{-1}\ K^{-1}$
- The absolute minimum temperaturefor an ideal gas, is found to be– 273.15 °C and is designated as absolute zero.

- The size of the unit for Kelvin temperature isthe same celsius degree, so temperature on thesescales are related by $T = t_C + 273.15$
- A change in the temperature of a bodycauses change in its dimensions. The increasein the dimensions of a body due to the increasein its temperature is called thermal expansion.The expansion in length is called linearexpansion. The expansion in area is called areaexpansion. The expansion in volume is calledvolume expansion.
- If the substance is in the form of a long rod,then for small change in temperature, ΔT, thefractional change in length, $\Delta l/l$, is directlyproportional to ΔT.
- $(\Delta l/l) = \alpha 1 \Delta T$

  where $\alpha 1$ is known as the coefficient of linearexpansion.
- The fractional change in volume, $\Delta V/V$, of a substance for temperature change ΔT and define the coefficient of volume expansion, α_V as

  $\alpha_V = (\Delta V/V)\ (1/\Delta T)$
- $\alpha_V = 1/T$ for ideal gas.

- The change in temperature of a substance, when a given quantity of heat is absorbed or rejected by it, is characterised by a quantity called the **heat capacity** of that substance. We define heat capacity, S of a substance as

  $S = \Delta Q/\Delta T$

  where ΔQ is the amount of heat supplied to the substance to change its temperature from T to $T + \Delta T$.
- Everysubstance has a unique value for the amount ofheat absorbed or rejected to change thetemperature of unit mass of it by one unit. Thisquantity is referred to as the **specific heatcapacity** of the substance.

  $s = S/m = (1/m)(\Delta Q/\Delta T)$

  The **specific heat capacity** is the property of the substance which determines the change inthe temperature of the substance when a given quantity of heatis absorbed (or rejected) by it. It is defined as the amount of heat per unit mass absorbed orrejected by the substance to change itstemperature by one unit. It depends on thenature of the substance and its temperature.

  The SI unit of specific heat capacity is $J\ kg^{-1}\ K^{-1}$.

  If the amount of substance is specified interms of moles μ, instead of mass *m* in kg, wecan define heat capacity per mole of thesubstance by

C = S/μ

where *C* is known as **molar specific heatcapacity** of the substance.

- A device in which heatmeasurement can be made is called acalorimeter.
- The change of state from solid to liquid iscalled melting and from liquid to solid is calledfusion. It is observed that the temperatureremains constant until the entire amount of thesolid substance melts. That is, both the solidand liquid states of the substance coexist inthermal equilibrium during the change ofstates from solid to liquid. The temperatureat which the solid and the liquid states of thesubstance in thermal equilibrium with eachother is called its melting point. It ischaracteristic of the substance. It also dependson pressure. The melting point of a substanceat standard atmospheric pressure is called itsnormal melting point.
- The change of state from liquid to vapour (orgas) is called vaporisation.
- The temperature at which the liquid and thevapour states of the substance coexist is calledits boiling point.
- The change from solid state to vapourstate without passing through the liquid stateis called sublimation, and the substance is saidto sublime. Dry ice (solid CO2) sublimes, so alsoiodine. During the sublimation process both the solid and vapour states of a substance coexistin thermal equilibrium.

- if mass m of a substanceundergoes a change from one state to the other,then the quantity of heat required is given by

  $Q = m L$

  or $L = Q/m$

  where L is known as latent heat and is acharacteristic of the substance. Its SI unit isJ kg^{-1}. The value of L also depends on thepressure.
- Conduction is the mechanism of transfer of heatbetween two adjacent parts of a body becauseof their temperature difference.
- the rateof flow of heat (or heat current) H is proportionalto the temperature difference (TC – TD) and thearea of cross section A and is inverselyproportional to the length L :
- $H = KA \{(TC – TD)/L\}$

  The constant of proportionality K is called thethermal conductivity of the material.

Sample Examples

- Convection is a mode of heat transfer by actualmotion of matter. It is possible only in fluids.Convection can be natural or forced. In naturalconvection, gravity plays an important part.When a fluid is heated from below, the hot partexpands and, therefore, becomes less dense.Because of buoyancy, it rises and the uppercolder part replaces it. This again gets heated,rises up and is replaced by the colder part ofthe fluid. The process goes on. This mode ofheat transfer is evidently different fromconduction. Convection involves bulk transportof different parts of the fluid.
- Newton’s Law of Cooling says that the rate of cooling of a body is proportional to theexcess temperature of the body over the surroundings :

  $dQ/dt = -k(T_2 – T_1)$

  Where T1 is the temperature of the surrounding medium and T2 is the temperature ofthe body.

- A blacksmith fixes iron ringon the rim of the wooden wheel of a bullockcart. The diameter of the rim and the iron ring are 5.243 m and 5.231 m respectivelyat 27 °C. To what temperature should thering be heated so as to fit the rim of thewheel?

  Solution

  Given, $T_1 = 27$ °C

  $L_{T1} = 5.231$ m

  $L_{T2} = 5.243$ m

  So, $L_{T2} = L_{T1} [1+\alpha_l (T_2 - T_1)]$

  $5.243 \text{ m} = 5.231 \text{ m} [1 + 1.20\times10^{-5} \text{ K}^{-1} (T_2 - 27 \text{ °C})]$

  or $T_2 = 218$ °C.

- A sphere of aluminium of0.047 kg placed for sufficient time in avessel containing boiling water, so that thesphere is at 100 °C. It is then immediatelytransferred to 0.14 kg copper calorimetercontaining 0.25 kg of water at 20 °C. Thetemperature of water rises and attains asteady state at 23 °C. Calculate the specificheat capacity of aluminium.

  Solution

  Mass of aluminium sphere (m_1) = 0.047 kg

  Initial temp. of aluminium sphere = 100 °C

  Final temp. = 23 °C

  Change in temp (ΔT) = (100 °C - 23 °C) = 77 °C

  Let specific heat capacity of aluminium be s_{Al}

  The amount of heat lost by the aluminium sphere = $m_1 s_{Al} \Delta T$ = 0.047kg*s_{Al}* 77 C

  Mass of water (m_2) = 0.25 kg

  Mass of calorimeter (m_3) = 0.14 kg

  Initial temp. of water and calorimeter = 20 °C

  Final temp. of the mixture = 23 °C

Change in temp. (ΔT2) = 23 °C – 20 °C = 3 °C

Specific heat capacity of water (sw) = 4.18 × 103 J kg^{-1} K^{-1}

Specific heat capacity of copper calorimeter = 0.386 × 103 J kg–1 K–1

The amount of heat gained by water and calorimeter = m2 sw ΔT2 + m3scuΔT2 = (m2sw + m3scu) (ΔT2)

= 0.25 kg ×4.18 × 103 J kg^{-1} K^{-1}+ 0.14 kg × 0.386 × 103 J kg^{-1} K^{-1}) (23 °C – 20 °C)

In the steady state heat lost by the aluminium sphere = heat gained by water + heat gained by calorimeter.

So, 0.047 kg × sAl × 77 °C = (0.25 kg × 4.18 × 103 J kg^{-1} K^{-1}+ 0.14 kg × 0.386 × 103 J kg^{-1} K^{-1})(3 °C)

sAl = 0.911 kJ kg^{-1} K^{-1}