Temperature and Thermal EQUILIBRIUM

(1)

When a substance is heated and becomes 'hotter' i.e. the temperature of the substance is increased, several of its physical properties undergo measurable change. These property changes include the expansion of solids, liquids and gases maintained at constant pressure, the increase in pressure of gases at constant volume, the increase in electrical resistance of wires, the generation of thermoelectric currents in thermocouple circuits and the change in colour of glowing objects. These thermometric properties have all been used in the construction of thermometer.

It is useful in thermodynamic to introduce the notion of a system. A system is in thermal equilibrium with its surround when it neither gain heat energy from nor losses heat energy to those surroundings. Two systems that are in thermal contact are in thermal equilibrium with each other when neither gains heat energy from the other.

FABEKU B. B

Zeroth Law of Thermodynamic

If A and B are each in thermal equilibrium with a third C, then A and B are in thermal equilibrium with each other.

Temperature is a measure of the degree of hotness or coldness of a body. The higher the temperature of an object, the hotter it feels to the touch. On a microscopic scale, temperature is directly related to the motion of the molecules making up a body. In fluid, where the molecules move about randomly, an increase in average speed of the molecules is manifested

as a rise in the temperature of the fluid. An increase in te-
rature of a solid body is associated with a increase in the av-
age speed of vibration of its molecules.

Measurement of Temperature

A thermometer is a device with which the temperature of a b
can be measured. Direct temperature measurements are based on a
of the easily measurable properties of matter that changes the tem-
rature. Among these are

- i. Volume of a liquid
- ii. Length of a rod
- iii. Electrical resistance of a wire
- iv. The pressure of a gas kept at constant volume
- v. The volume of a gas kept at constant pressure.
- vi. The color of a lamp filament

Any of these properties can be used in the construction of a thermometer.

Temperature Scale

Two common scales, which are used for temperature measurement are the Fahrenheit and Celsius (or Centigrade) scales. The temperature of melting ice and boiling water are 32°F and 212°F respectively on the Fahrenheit scale, and 0°C and 100°C on the Celsius scale. A temperature T_F on the Fahrenheit scale can be converted to its Celsius equivalent T_c (and vice-versa) through the equation

$$\boxed{T_c = \frac{5}{9}(T_F - 32)}$$

An absolute scale of temperature on which measurements are made in Kelvin is one in which the lowest possible temperature is zero (0 K). For a given Celsius temperature T

equivalent absolute temperature, T_K on the absolute scale given by ②

$$T_K = T_c + 273.15$$

Thus the temperature of melting ice and boiling water would be 273.15 K and 373.15 K respectively on the absolute scale.

In engineering Practice, the Rankine temperature scale is sometimes used. Thus on the Rankine scale.

$$T_R = \frac{9}{5} T_c = T_F + 459.68$$

Thermal Expansion

Most substances expand when heated at constant pressure. Thus, when the temperature is increased the average distance between atoms increases, which leads to an expansion of the whole solid body. The change in any linear dimension of the solid, such as length, width or thickness is called a linear expansion. If the length of this linear dimension is l, the change in length, arising from a change in temperature dt is dl. It's found from experiment that if dt is small enough this change in length dl. Hence, we can write

$$dl = \alpha l dt$$

where α is called the coefficient of linear expansion. It has different values for different materials. It follows that

$$\alpha = \frac{dl}{l dt}$$

Strictly speaking, the value of α depends on the actual temperature. For example the value of α for stainless

steel is $0.81 \times 10^{-5}/^\circ c$ at $100^\circ c$ and is $1.43 \times 10^{-5}/^\circ c$ at

The fractional change in area A per degree temperature is 2α i.e

$$dA = 2\alpha A dt$$

And the fractional change in volume V per degree temperature change is 3α i.e

$$dV = 3\alpha V dt$$

because the shape of a fluid is not definite. only the change in volume with temperature is significant. If we let β represents the Coefficient of Volume expansion for a liquid i.e

$$\beta = \frac{dv}{V dt}$$

For a particular substance, the volume expansion coefficient is just three times the linear expansion Coefficient

$$\beta = 3\alpha$$

However the most Common liquid, water does not behave like other liquids. Above $4^\circ c$ water expands as the temp. rises although not linearly. Between $0^\circ c$ and $4^\circ c$ however, water Contracts with increasing temp. instead of expanding as other Common liquids do. This is Called anomalous behavior of water.

Example At what temp. will the Celsius and Fahrenheit temp. scales record the same reading.

Example 2 A steel rod increases its length by 5mm when the temperature increases by $10^\circ c$ - what is the initial length of the rod. if the Coefficient of linear expansion for steel is 1.1×10^{-5} per $^\circ c$. 45.45m

Heat Transfer

If two bodies at initial different temperatures are brought to thermal contact, thermal equilibrium can be attained only if heat is able to flow from the hotter to the cooler body. The three processes by which heat is transferred between two regions at different temperatures are conduction, convection and radiation.

Conduction

If one end of a metal rod is placed in a hot liquid, the other end soon becomes warmer and warmer as a result of the transfer of heat, through conduction, from the hot to the cold end.

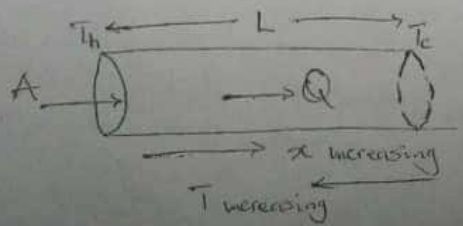
For a rod of uniform cross-sectional area A, which is exposed to a temperature gradient $\frac{dT}{dx}$, the rate of heat flow Q by conduction is directly proportional to the cross sectional area A of the rod and to the temperature gradient along the rod i.e. $Q_K \propto A \cdot \frac{dT}{dx}$

$$Q_K = -KA\frac{dT}{dx}$$

where K the proportionality constant, is referred to as the thermal conductivity of the rod material. Since T decreases as x increases $\frac{dT}{dx}$ is negative & Q is therefore positive. If the rod has length and the temperature decreases uniformly from T_H at the hot end to T_c at the cold end, then $\frac{dT}{dx} = \frac{T_c - T_h}{L}$, then Q becomes

$$Q = \frac{KA(T_h - T_c)}{L}$$

The unit of K is Watt/m.K or J/s.m.K



When a quantity of heat dQ is transferred in a time dt, the rate of flow is $\frac{dQ}{dt}$ called heat current (H)

$$H = \frac{dQ}{dt} = KA\frac{T_h - T_c}{L}$$

... i.e. for two systems A and B in thermal contact with each other the composite system surrounded by adiabatic walls, heat gained by one system is equal to the heat lost by the B system.

Quantity of Heat and Specific Heat

The ratio of the amount of heat energy ΔQ supplied to a body to its corresponding temperature rise ΔT is called the heat capacity i.e

$$C = \frac{\Delta Q}{\Delta T}$$

The specific heat capacity c is the quantity of heat Q required to raise the temperature of a mass (m) from T_1 to T_2, found to be approximately proportional to the temperature change $\Delta T = T_2 - T_1$.

The follow expression is used to determine the specific heat of material

$$c = \frac{\text{heat-capacity}}{\text{mass}} = \frac{\Delta Q}{m\Delta T}$$

$$\Delta Q = mc\Delta T$$

where c is the specific heat of a material

The unit of quantity of heat is Calorie, which is defined as the quantity of heat which raises the temperature of 1g of water by 1°C. Though, the Joule is the unit used nowadays and this is approximately

$$4.2 \text{ joules} = 1 \text{ calorie}$$
$$1 \text{ kcal} = 1000 \text{ cal} = 4200 \text{ J}$$

Thus to raise the temperature of mass m, of the substance by T, we require a quantity of heat Q given by

$$Q = mc\Delta T \qquad c = \frac{Q}{m\Delta T} \ \text{J g}^{-1} \text{K}^{-1}$$

The total quantity of heat Q which must be supplied to raise the temperature of mass m of the substance from T_1 to T_2 is

$$Q = \int_{T_1}^{T_2} dQ = \int_{T_1}^{T_2} mc\,dT = mc\int_{T_1}^{T_2} dT$$

$$Q = mc(T_2 - T_1)$$

Convection

Convection is the transfer of heat by mass motion of fluid from one region of space to another. e.g hot water heater, hot air movement, cooling system of automobile & flow of blood in human body

$$\boxed{Q_c = hA\Delta T}$$

where h = convection coefficient = 3.45 J/sm²K

Radiation

Radiation is the transfer of heat by electromagnetic waves such as visible light, infrared and ultraviolet radiation. The heat transfer can occur even if there were nothing but vacuum between you and the heat source. When electromagnetic waves with wavelengths which are a little longer than that of light (i.e infrared radiation) impinge on a body which is not transparent to them they are absorbed and converted into heat energy. The heat energy thus produced is referred to as radiant heat.

The intensity of radiant heat emitted by a surface depends on the nature as well as the temperature of the surface. For a surface of area A at absolute temperature T_1, the rate at which radiant heat is emitted is

$$\boxed{Q_r = \varepsilon \sigma A T_1^4}$$

where σ is the Stefan-Boltzmann Constant, which is equal to $5.6696 \times 10^{-8}\ W/m^2K^4$. The parameter ε is the emissivity of the surface lies between 0 and 1, depending on the nature of the surface

Exercise:

1. Determine the quantity of heat, which is conducted in 30 mins through an iron plate 2.0 cm thick, and 0.10 m² in area if the temps of the two sides are 0°C and 25°C. The coefficient of thermal conductivity of iron is 50.4 J/smK. [Ans = 9.07 × 10⁶ J]

2. The inside surface of a wall of a house is maintained at a constant temp of 25°C. How much heat is lost by natural convection from the 8.0m × 4.0 wall in 24 hours if the average convection coefficient is 3.45 J…

~~temperature of mass m of the substance.~~

The molar heat capacity or molar specific heat of a substance is the heat required to raise the temperature of 1 mole of the substance by 1°C. For n moles of the substance therefore,

$$\boxed{\Delta Q = nC\Delta T}$$

By definition, the number of moles (n) in a substance of mass m,

$$n = m/M$$

where M is the molecular weight of the substance. The equivalent total quantity of heat using the molar heat capacity is

$$Q = \int_{T_1}^{T_2} nC\,dT$$

$$Q = nC(T_2 - T_1)$$

Unit for C is J/mol K. [$J\,mol^{-1}K^{-1}$]

Note that: Q (or ΔQ or dq) and ΔT (or dT) can be either +ve or −ve when it is positive (+ve), heat enters the body and it temperature increases and otherwise.

Specific heat of a body always depend on the initial temperature and the temperature interval.

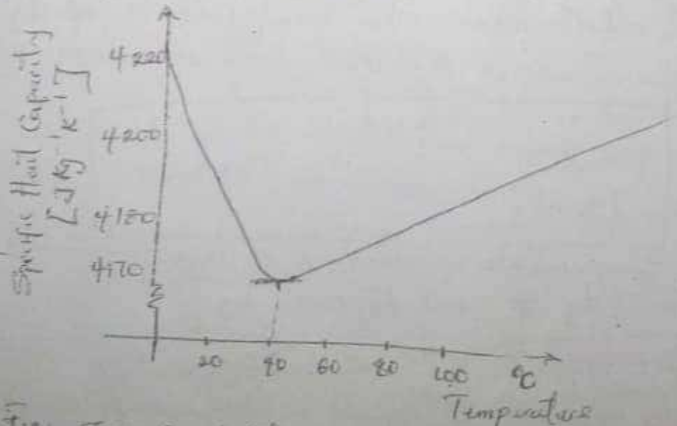


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Fig: Specific heat of water as a function of temp. The value of c varies by less than 1% between 0°C and 100°C