THERMAL EXPANSION OF MATERIALS
EXPANSION OF SOLIDS

Synopsis : TEMPERATURE

1. The invention of thermometer and development of the concept of temperature mark the beginnings of the science of thermodynamics.
2. The temperature of a body is a state which determines the direction of flow of heat or the degree of hotness of a body.
3. Heat is the cause and temperature is the effect.
4. A body at a higher temperature need not necessarily contain more heat.
5. Two bodies at the same temperature may contain different amounts of heat.
6. Two bodies containing the same amount of heat may be at different temperatures.
7. The direction of flow of heat from a body does not depend on its heat content but depends on its temperature.
8. In principle, any system whose properties change the temperature can be used as a thermometer.
9. There are four scales of temperature. They are Celsius scale, Fahrenheit scale, Reaumer scale and Kelvin (or Absolute or thermodynamic temperature) scale.
10. The most fundamental scale of temperature called Kelvin scale is based on the laws of thermodynamics.
11. The melting point of ice at standard atmospheric pressure is taken as the lower fixed point.
12. The boiling point of water at standard pressure is taken as the upper fixed point. The upper fixed point is determined by using Hypsometer.
13. The distance between the lower and upper fixed points is divided into definite equal divisions.
14. Different scales of temperature.
15. The reading on one scale can be readily converted into corresponding one or the other by the relation $\frac{K-273}{100}=\frac{C}{100}=\frac{F-32}{180}=\frac{R}{80}$
16. If in a certain arbitrary scale of temperature, p° is the lower fixed point and q° is the upper fixed point, any temperature x in this scale can be converted to Celsius or Fahrenheit scale by using the formula $\frac{C}{100}=\frac{x-p}{q-p}=\frac{F-32}{180}$
17. The differences of temperature on different scales can be converted using the formula $\frac{\Delta K}{100}=\frac{\Delta C}{100}=\frac{\Delta F}{180}=\frac{\Delta R}{80}$
18. Different types of thermometers and their ranges :

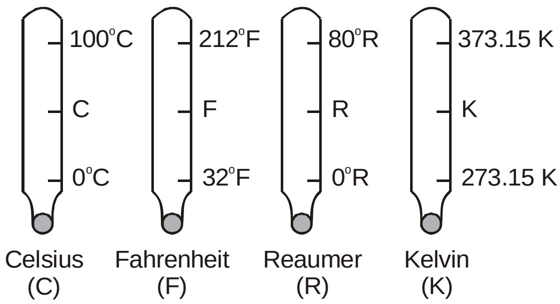
Clinical thermometer	–95°F to 110°F
Mercury t4hermometer	–38°C to 350°C
Alcohol thermometer	–110°C to 78°C
Hydrogen gas thermometer	–260°C to 1600°C
Platinum resistance thermometer	–200°C to 1200°C
Pyrometer very high temperatures	

19. Advantages of mercury as a thermometric fluid.
    i) Mercury remains as a liquid over a wide range of temperature
    ii) Pure mercury can be readily and easily obtained.
    iii) Its vapour pressure at ordinary temperature is negligible.

iv) It has high conductivity and low thermal capacity. So it quickly attains the temperature of the body by taking a negligibly small quantity of heat.

v) It does not wet glass and is opaque.

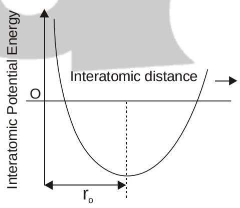
20. Of all the thermometers, gas thermometers are more sensitive because of their high volume expansion. They have the same scale for all gases.
21. Using a constant volume hydrogen thermometer, temperatures ranging from –200°C to 1100°C can be measured. It is generally used to calibrate other thermometers.
22. To have more surface contact with heat, the thermometric bulb will be in the shape of a cylinder.



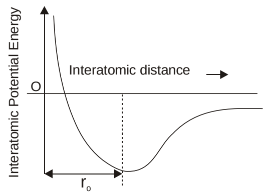
23. To determine the maximum and minimum temperatures attained during a day at a place, Six's maximum and minimum thermometer is used.
24. If X is any thermometric property such as pressure or volume or resistance which has values at 0°, 100° and t° on any scale as X_0, X_{100} and X_t, then $t = \left(\frac{X_t - X_0}{X_{100} - X_0}\right)100$.
25. Temperatures on the Celsius scale denoted by the symbol °C (read "degrees Celsius"). Temperature changes and temperature differences on the Celsius scale are expressed in C° (read "Celsius degrees"). For eg: 20°C is a temperature and 20 C° is a temperature difference. In general, all substances whether they are in the form of solids, liquids or gases expand on heating except water between 0°C and 4°C and some aqueous solutions. This is known as thermal expansion.

EXPANSION OF SOLIDS :

26. Solids expand on heating due to increased atomic spacing.
27. A solid can be considered as periodic arrangement of atoms in the form of lattice.
28. At any particular temperature, the atoms are in a specific state of vibration about a fixed point called as equilibrium position in the lattice.
29. As the temperature increases, the amplitude of vibration of the atoms increases.
30. If the lattice vibrations are purely harmonic the potential energy curve is a symmetric parabola and there is not thermal expansion.



31. If the lattice vibrations are anharmonic, the potential energy of an oscillator is an asymmetric function of its position and thermal expansion is observed.



32. Coefficient of linear expansion (α) : The ratio of increase in length per one degree rise in temperature to its original length is called coefficient of linear expansion.

$$\alpha = \frac{l_2 - l_1}{l_1(t_2 - t_1)}$$

Unit of α is $C^{o^{-1}}$ or K^{-1}

33. The change in length is calculated using $\Delta L = L\,\alpha\,\Delta t$

34. Coefficient of area or superficial expansion (β) : The increase in area per unit area per one degree rise in temperature is called coefficient of areal expansion.

    $\beta = \dfrac{a_2 - a_1}{a_1(t_2 - t_1)}$

    Unit of β is ${C^o}^{-1}$ or K^{-1}
35. The change in area is calculated using formula $\Delta a = a\ \beta\ \Delta t$.
36. The coefficient of volume or cubical expansion (γ) is the increase in volume per unit volume per degree rise in temperature.

    $\gamma = \dfrac{V_2 - V_1}{V_1(t_2 - t_1)}$

    Unit of γ is ${C^o}^{-1}$ or K^{-1}
37. The change in volume is calculated using formula $\Delta V = V\ \gamma\ \Delta t$.
38. For all isotropic substances (solids which expand in the same ratio in all directions) $\alpha : \beta : \gamma = 1:2:3$ or $\gamma = 3\alpha$; $\beta = 2\alpha$; $\gamma = \alpha + \beta$.
39. If α_x, α_y and α_z represent the coefficients of linear expansion for an isotropic solids (solids which expand differently in different directions) in x, y and z directions respectively, then $\gamma = \alpha_x + \alpha_y + \alpha_z$ and the average coefficient of linear expansion $\alpha = \dfrac{\alpha_x + \alpha_y + \alpha_z}{3}$.
40. The numerical value of coefficient of linear expansion of a solid depends on the nature of the material and the scale of temperature used.
41. The numerical value of coefficient of linear expansion of a solid is independent of physical dimensions of the body and also on the unit of length chosen.
42. The increase in length or linear expansion of a rod depends on nature of material, initial length of rod and rise of temperature.
43. The numerical value of α or β or γ in the units of per °C is 9/5 times its numerical value in the units of per °F.
44. α per °F$= \dfrac{5}{9}.\alpha$ per °C.
45. α per °R$= \dfrac{5}{4}.\alpha$ per °C.
46. Variation of density with temperature : The density of a solid decreases with increase of temperature. $d_t = \dfrac{d_o}{1 + \gamma t}$ or $d_t \approx d_o(1 - \gamma t)$ where d_o is density at 0°C.
47. If R_1 and R_2 are the radii of a disc or a plate at t_1°C and t_2°C respectively then $R_2 = R_1(1 + \alpha(t_2 - t_1))$.
48. A metal scale is calibrated at a particular temperature does not give the correct measurement at any other temperature.
    a) When scale expands correction to be made $\Delta l = L\ \alpha\ \Delta t$, correct reading=$L + \Delta l$
    b) When scale contracts correction to be made $\Delta l = L\ \alpha\ \Delta t$, correct reading=$L - \Delta l$. L=measured value.
    c) $L_{measured} = L_{true}[1 - \alpha(\Delta t)]$
49. When a metal rod is heated or cooled and is not allowed to expand or contract thermal stress is developed.

Thermal force $F=YA\,\alpha\,(t_2–t_1)$

Thermal force is independent of length of rod.

Thermal stress $\sigma=Y\,\alpha\,(t_2–t_1)$

Y=Young's modulus

α=coefficient of linear expansion

$t_2–t_1$=difference of temperature

A=area of cross-section of the metal rod.

For same thermal stress in two different rods heated through the same rise in temperature, $Y_1\alpha_1=Y_2\alpha_2$.

50. Barometer with brass scale :

    Relation between faulty and actual barometric height is given by $h_2=h_1[1+(\alpha_s–Y_{Hg})(t_2–t_1)]$

    h_1=height of barometer at t_1°C where the scale is marked

    h_2=height of barometer at t_2°C where the measurement is made

    γ_{Hg}=real coefficient of expansion of mercury

    α_s=coefficient of linear expansion of scale

51. Pendulum clocks lose or gain time as the length increases or decreases respectively.

    The fractional change=$\frac{\Delta T}{T}=\frac{\alpha\Delta t}{2}$.

    The loss or gain per day=$\frac{\alpha\Delta t}{2}$x86400 seconds.

52. The condition required for two rods of different materials to have the difference between the lengths always constant is $L_1\alpha_1=L_2\alpha_2$.
53. A hole in a metal plate expands on heating just like a solid plate of the same size.
54. A cavity of a solid object expands on heating just like a solid object of the same volume.
55. If a hollow pipe and a solid rod of same dimensions made of same material are heated to the same rise in temperature, both expand equally.
56. If a thin rod and a thick rod of same length and material are heated to same rise in temperature, both expand equally.
57. If a thin rod and a thick rod of same length and material are heated by equal quantities of heat, thin rod expands more than thick rod.
58. A rectangular metal plate contains a circular hole. If it is heated, the size of the hole increases and the shape of the hole remains circular.
59. A metal plate contains two holes at a certain distance apart from each other. If the plate is heated, the distance between the centers of the holes increases.
60. The change in the volume of a body, when its temperature is raised, does not depend on the cavities inside the body.

Applications of linear expansion :

61. Platinum (or monel) is used to seal inside glass because both have nearly equal coefficients of linear expansion.
62. Iron or steel is used for reinforcement in concrete because both have nearly equal coefficients of expansion.

63. Pyrex glass has low α. Hence combustion tubes and test tubes for hating purpose are made out of it.
64. Invar steel (steel+nickel) has very low α. So it is used in making pendulum clocks, balancing wheels and measuring tapes. (Composition of invar steel is 64% steel and 36% nickel).
65. Metal pipes that carry steam are provided with bends to allow for expansion.
66. Telephone wires held tightly between the poles snap in winter due to induced tensile stress as a result of prevented contraction.
67. Thick glass tumbler cracks when hot liquid is poured into it because of unequal expansion.
68. Hot chimney cracks when a drop of water falls on it because of unequal contraction.
69. A brass disc snuggly fits in a hole in a steel plate. To loosen the disc from the hole, the system should be cooled.
70. To remove a tight metal cap of a glass bottle, it should be warmed.
71. While laying railway tracks, small gaps are left between adjacent rails to allow for free expansion without affecting the track during summer. Gap to be left $(\Delta l)=\alpha l\Delta t$=expansion of each rail.
72. Concrete roads are laid in sections and expansion channels are provided between them.
73. Thermostat is a device which maintains a steady temperature.
74. Thermostats are used in refrigerators, automatic irons and incubators.
75. Thermostat is a bimetallic strip made of iron and brass. The principle involved is different materials will have different coefficients of linear expansion.
76. A bimetallic strip is used in dial-type thermometer.
77. If an iron ring with a saw-cut is heated, the width of the gap increases.
78. Barometric scale which expands or contracts measures wrong pressure. On expansion the true pressure is less than measured pressure.

    $P_{true}=P_{measured}[1-(\gamma-\alpha)t]$

    where γ=coefficient of cubical expansion of mercury

    α=coefficient of linear expansion of the material used in making the scale

    t=rise of the temperature
79. When a straight bimetallic strip is heated it bends in such a way that the more expansive metal lies on the outer side. If d is the thickness of the each strip in a bimetallic strip, then the radius of the compound strip is given by $R=\frac{d}{(\alpha_2-\alpha_1)\Delta t}$.

EXPANSION OF LIQUIDS

20. Liquids expand on heating except water between 0°C and 4°C.
21. The expansion of liquids is greater than that of solids (about 10 times).
22. Liquids do not possess any definite shape and require a container to hold them. Hence only cubical expansion is considered.
23. Since heat effects both the liquid and the container the real expansion of a liquid cannot be detected directly.
24. For liquids there are two types of cubical expansion

    i) coefficient of apparent expansion (γ_a)

ii) coefficient of real or absolute expansion (γ_r)

25. Coefficient of apparent expansion of a liquid is the ratio of the apparent increase in volume per 1°C rise of temperature to its initial volume.

$$\gamma_a = \frac{\text{apparent increase in volume}}{\text{original volume x rise in temperature}}$$

The unit of γ_a is $°C^{-1}$.

26. Coefficient of real expansion is the ratio between real increase in volume per 1°C rise of temperature and the original volume of the liquid.

$$\gamma_r = \frac{\text{real increase in volume}}{\text{original volume x rise in temperature}}$$

$$\gamma_r = \frac{V_2 - V_1}{V_1(t_2 - t_1)}$$

The unit of γ_r is $°C^{-1}$.

27. $\gamma_r = \gamma_a + \gamma_{vessel} = \gamma_a + 3\alpha$.
28. If γ_v=+ve and $\gamma_r<\gamma_v$, γ_a=–ve, the level decreases continuously when heated.
29. If γ_v=+ve and $\gamma_r=\gamma_v$; $\gamma_a=0$, the level will not change when heated.
30. If γ_v=+ve and $\gamma_r>\gamma_v$; γ_a=+ve, the level first falls and then rise when heated.
31. If $\gamma_v=0$; $\gamma_r=\gamma_a$, the level will increase continuously when heated.
32. If γ_v=–ve, $\gamma_a>\gamma_r$, the level will increase continuously when heated.
33. The real expansion of a liquid does not depend upon the temperature of the container.
34. The apparent expansion of liquid depends on

    a) initial volume or liquid, b) rise in temperature

    c) nature of liquid and d) nature of container.
35. γ_{ap} is determined using specific gravity bottle or pyknometer or weight thermometer.

$$\gamma_a = \frac{\text{mass expelled}}{\text{mass remaining x rise of temperature}}$$

$$\gamma_a = \frac{\text{weight of liquid expelled}}{\text{weight of remaining liquid x rise of temperature}}$$

$$\gamma_a = \frac{W_2 - W_3}{(W_3 - W_1)(t_2 - t_1)}$$

36. Sinker's method $\gamma_{app} = \frac{m_1 - m_2}{m_2 t_2 - m_1 t_1} /^o C$

    m_1=loss of weight of body in liquid at t_1°C

    m_2=loss of weight of body in liquid at t_2°C
37. To keep the volume of empty space in a vessel (volume v_g) constant at all temperatures by pouring certain amount of a liquid of volume v_l, the condition is $v_l\gamma_l = v_g\gamma_g$ where γ_l=coefficient of cubical expansion of liquid and γ_g=coefficient of cubical expansion of vessel.
38. The fraction of the volume of a flask that must be filled with mercury so that the volume of the empty space left may be the same at all temperatures is 1/7.
39. The density of a liquid usually decreases when heated. If d_1 and d_2 are the densities of a liquid at 0°C and t°C respectively, then

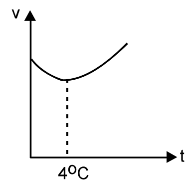
$d_t = \frac{d_o}{1+\gamma_r t}$; $d_t = d_o(1-\gamma_r t)$;

Accurate formula Approximate formula

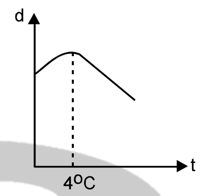
$\gamma_r = \frac{d_1 - d_2}{d_1 t_2 - d_2 t_1} /^o C$

ANOMALOUS EXPANSION OF WATER :

40. When water at 0°C is heated, its volume decreases upto 4°C and from 4°C its volume increases with the increase of temperature. This peculiar behaviour of water is called anomalous expansion of water. Due to the formation of more number of hydrogen bonds, water has anomalous expansion.



41. As the temperature increases from 0°C to 4°C, the density increases and as the temperature further increases the density decreases. Hence water has maximum density at 4°C.



42. Specific volume is the volume occupied by unit mass. It is the reciprocal of density. As the temperature increases from 0°C to 4°C, the specific volume decreases and as the temperature further increases, the specific volume increases.
43. Hope's apparatus is used to demonstrate that water has maximum density at 4°C.
44. Rubber shows anomalous expansion like water.
45. Dilatometer is used to prove anomalous expansion of water.
46. Aquatic animals are surviving in cold countries due to the anomalous expansion of water.
47. During winter, in cold countries, even if the temperature falls far below 0°C, the water in the frozen lakes or seas at the bottom remains at 4°C.
48. When water freezes, it expands and consequently water pipes burst in winter.
49. When water at 4°C is filled to the brim of a beaker, then it over flows when it is either cooled or heated.
50. A beaker contains water at 4°C and a piece of ice is floating on it. When the ice melts completely, the level of water increases.
51. When a solid is immersed in a liquid (which does not show anomalous expansion) its apparent weight increases with the increase of temperature.
52. If W is the weight of a sinker in water at 0°C and W_1 is weight in water at 4°C, then $W_1 << W$.
53. As the temperature of water is increased from 0°C to 4°C, the apparent weight of a body decreases. At 4°C the apparent weight is minimum. On further heating the apparent weight increases.
54. Water has positive coefficient of expansion above 4°C and negative coefficient below 4°C.
55. At 4°C the coefficient of expansion of water is zero.
56. A wooden block is floating in water at 0°C. When the temperature of water is increased, the volume of the block below water surface decreases upto 4°C and beyond 4°C it increases.
57. In a mercury thermometer, the coefficient of apparent expansion of mercury can be determined by $\gamma_a = \frac{\pi R^2 l}{v\Delta t}$ where l=length of the stem, v=initial volume of mercury in the bulb and Δt=rise in temperature.

DETERMINATION OF γ_{real} OF A LIQUID :

58. Specific gravity bottle method $\gamma_{real} = \gamma_{app} + \gamma_{vessel}$.

59. Dulong Petit method (U-tube method)

$$\gamma_{real} = \frac{h_t - h_0}{h_0 t} /^o C \text{ (or) } \gamma_{real} = \frac{h_2 - h_1}{h_1 t_2 - h_2 t_1}.$$

h_t=height of liquid column in limb at t°C

h_0=height of liquid column in limb at 0°C

60. Regnault's apparatus

$$\gamma_{real} = \frac{h_2 - h_1}{[H - (h_2 - h_1)t]} /^o C$$

H=height of liquid in wide tubes

$h_2 - h_1$=difference in heights of liquid columns at t°C and 0°C in U-tube

61. The corrected height of a barometer is given by the relation $H = h_t[1 - (\gamma_r - \alpha)t]$ where H=height at 0°C; h_t=height at t°C; γ_r=coefficient of real expansion of the liquid and α=coefficient of linear expansion of the material of the scale.

EXPANSION OF GASES

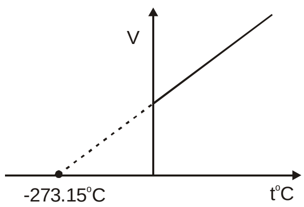
1. Pressure, volume and temperature are the three measurable properties of a gas. Change in one of these factors results in a change in the other two factors.
2. Pressure of a gas is measured by manometer Bourden gauge for high pressures and Mcleod gauge for low pressures. These work on Boyle's law.
3. Volume of a gas is measured by a gas burette or on **Eudiometer**.
4. A gas has neither unique shape nor unique volume. The gas completely occupies the vessel in which it is placed.

Coefficients of expansion of gas :

5. When a given mass of gas is heated under constant pressure, its volume increases with increase in temperature.
6. When a given mass of gas is heated under constant volume its pressure increases with increase in temperature. Hence gases have two types of coefficients of expansions.

   i) volume expansion coefficient

   ii) pressure expansion of coefficient

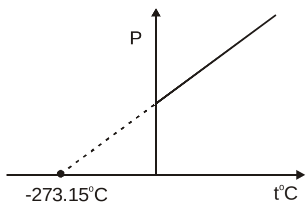


7. **Volume coefficient of a gas (α) :** At constant pressure the ratio of increase of volume per 1°C rise in temperature to its original volume at 0°C is called volume coefficient of a gas.

$$\alpha = \frac{V_t - V_0}{V_0 t} \quad \text{or} \quad \alpha = \frac{V_2 - V_1}{V_1 t_2 - V_2 t_1}$$

$V_t = V_0(1 + \alpha t)$

The unit of α is $°C^{-1}$ or K^{-1}.



8. **Pressure coefficient of a gas (β) :** At constant volume the ratio of increase of pressure per 1°C rise in temperature to its original pressure at 0°C is called pressure coefficient of gas. Unit is $°C^{-1}$ or K^{-1}.

$\beta = \frac{P_t - P_0}{P_0 t}$ or $\beta = \frac{P_2 - P_1}{P_1 t_2 - P_2 t_1}$

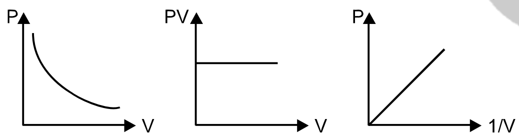
$P_t = P_0(1+\beta t)$

9. **Regnault's apparatus** is used to determine the volume coefficient of a gas.
10. **Jolly's bulb apparatus** is used to determine the pressure coefficient of a gas.
11. Volume coefficient and pressure coefficient of a gas are equal and each equal to $\frac{1}{273}$/°C or 0.0036/°C for all gases.
12. P-t graph or V-t graph is straight line intersecting the temperature axis at –273.15°C. This temperature is called absolute zero. (0 K)
13. Absolute zero is the temperature at which the volume of a given mass of a gas at constant pressure or the pressure of the same gas at constant volume becomes zero.
14. The lowest temperature attainable is –273.15°C or 0 K.
15. The scale of temperature on which the zero corresponds to –273°C and each degree is equal to the Celsius degree is called the absolute scale of temperature or thermodynamic scale of temperature.

    T K = t+273.15°C

    There is no negative temperature on Kelvin scale.
16. **Boyle's law :** At constant temperature, the pressure of a given mass of a gas is inversely proportional to its volume. $P \propto \frac{1}{V}$ or PV = K (n, T are constant) or $P_1V_1 = P_2V_2$. In PV = K, the value of K depends on the mass and temperature of the gas and the system of units.
17. Boyle's law can also be defined as follows. At constant temperature, the pressure of a given mass of gas is directly proportional to its density.

    $P \propto d$ or $\frac{P}{d} = K$ or $\frac{P_1}{d_1} = \frac{P_2}{d_2}$.



18. P-V graph at a constant temperature (isothermal) is a rectangular hyperbola.
19. PV-V graph is a straight line parallel to volume axis.
20. P–$\frac{1}{V}$ graph is a straight line passing through the origin.
21. Many gases obey Boyle's law only at high temperatures and low pressures.
22. When a Quill tube is kept vertical with the open end upwards, the pressure exerted by gas column is (H+h) where H is atmospheric pressure and h is the length of mercury pellet.
23. When a Quill tube is kept horizontal, the pressure exerted by gas column is equal to atmospheric pressure.
24. When a Quill tube is kept vertical with the open end downwards, the pressure exerted by the gas column is (H–h).

25. When a Quill tube is kept inclined to the vertical at an angle θ and open end is upwards, then the pressure exerted by gas column is (H+hcos θ).
26. **Charles' law :** At constant pressure, the volume of a given mass of gas increases by 1/273th of its original volume at 0°C for every 1°C rise in temperature. (or) At constant pressure, the volume of a given mass of gas is directly proportional to the absolute scale of temperature. $V \alpha T$ or $\frac{V}{T} = K$ (at constant P)
27. V-T graph is a straight line passing through the origin.
28. V-t (in °C) graph is a straight line which when produced meets the temperature axis at –273.15°C or 0 K.
29. The pressure of a given mass of gas at constant volume increases by 1/273th of its original pressure at 0°C for every 1°C rise in temperature. (or) At constant volume, the pressure of a given mass of gas is directly proportional to absolute scale of temperature. This is also known as **Gay Lussac's law**. $P \alpha T$ or $\frac{P}{T} = K$ (at constant V)

Gas Equation :

30. Combining Boyle's law and Charle's law, the resulting expression is an equation of state for ideal gas.
31. For unit mass of a gas (1 gram or 1 kg)
    PV=rt is called 'Gas Equation'
    PV=mRT (for m grams)
32. "r" is called gas constant (or) specific gas constant.
33. The value of "r" depends on nature and mass of the gas.
34. S.I. unit of "r" is $JKg^{-1}K^{-1}$. Dimensional formula for "r" is $LT^{-2}\theta^{-1}$.
35. For one mole of a gas PV=RT is called universal (or) ideal (or) perfect gas equation.
36. The value of R is same for all gases irrespective of their nature.
37. If M is gram molecular mass of the gas, then r = R/m.
    $PV = \frac{m}{M}RT \Rightarrow PV = nRT$
    where n = no. of moles of gas.
38. S.I. unit of R is J $mole^{-1}K^{-1}$.
    Values of R=8.314 Jg $mole^{-1}K^{-1}$
    R = 8314 J kg $mole^{-1}K^{-1}$
    R = 0.0821 litre atmosphere $mole^{-1}K^{-1}$
    R = 8.314×10^7 ergs $mole^{-1}K^{-1}$
    R = 1.987 cal $mole^{-1}K^{-1}$

Significance of R:

39. The value of R gives the work done by one mole of any gas when it is heated under constant pressure through one degree Kelvin.
40. The value of R does not depend on the mass of gas or its chemical formula.

41. The fact that R is a constant for all gases is consistent with Avagadro's hypothesis that "equal volumes of all gases under same conditions of temperature and pressure contain equal number of molecules".

42. The value of universal gas constant per molecule is 1.38×10^{-23} J $mol^{-1}K^{-1}$

    $R = N_0K$, where K = Boltzmann's constant, N_0 = Avagadro's number

43. The gas equation in terms of density $\frac{P}{dT}$ =constant. Where d=density of ideal gas.

44. When pressure and volume are constant for given ideal gas.

    $m \alpha \frac{1}{T}$, $m \alpha \frac{K}{T}$, $\frac{m_1}{m_2} \alpha \frac{T_2}{T_1}$

45. Two vessels of volumes V_1 and V_2 contain air pressures P_1 and P_2 respectively. If they are connected by a small tube of negligible volume then the common pressure is $P = \frac{P_1V_1 + P_2V_2}{V_1 + V_2}$.

46. **Dalton's law of partial pressures :** The total pressure of a non-reacting mixture of gases is equal to the sum of the partial pressures.

    Partial pressure=mole fraction x total pressure.

48. Vapour is a gas which can be liquified by the application of pressure alone.

49. Critical temperature (T_c), critical pressure (P_c) and critical volume (V_c) are called critical constants of a gas.

50. The temperature above which a gas cannot be liquified by mere application of pressure is called **critical temperature**.

51. Gases below their critical temperature are called vapours and vapours above their critical temperature are called **gases**