THERMAL PROPERTIES OF MATTER

IDEAL GAS EQUATITION AND ABSOLUTE TEMPERATURE

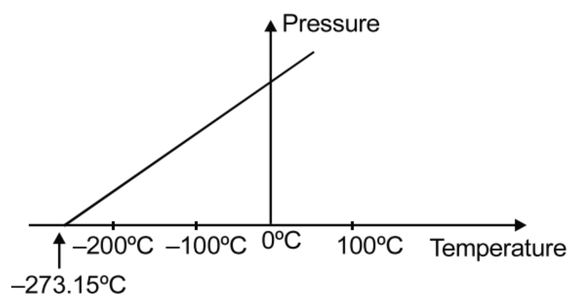
IDEAL GAS EQUATITION ABSOLUTE TEMPERATURE

Experiments consistently reveal that all gases, particularly at low densities, exhibit identical expansion behavior. In situations where temperature remains constant, the pressure and volume of a given quantity of gas follow a relationship expressed by the equation PV = constant, known as Boyle's law. On the other hand, when the pressure is maintained at a constant level, the volume of the gas is found to be directly proportional to its temperature, described by the equation V/T = constant, recognized as Charles' law. These two fundamental gas behaviors can be amalgamated into a singular relationship, resulting in the expression PV/T = constant.

This amalgamated relationship is commonly referred to as the ideal gas law and is denoted by the equation $\frac{PV}{T} = \mu R$, where:

- PV/T represents the pressure, volume, and temperature of the gas,
- μ signifies the number of moles of the gas,
- R is the universal gas constant (R = 8.31 J mol^{-1} K^{-1}).

The ideal gas law can also be expressed more generally as PV = μRT, offering a comprehensive representation of the interdependence among pressure, volume, temperature, and the number of moles of a gas in a given system.



The lowest achievable temperature, known as absolute zero, is equivalent to -273.15°C. This pivotal point forms the basis of the Kelvin temperature scale, also referred to as the absolute scale temperature.

In the calibration of various thermometers using ice-water and steam, a consensus is reached at 0°C and 100°C; however, discrepancies arise at intermediate points. These discrepancies become more pronounced beyond the steam and ice points. Notably, gas thermometers demonstrate closely aligned temperature measurements, even at considerable distances from the calibration points.

One specific type of gas thermometer, the constant-volume gas thermometer, maintains a fixed gas volume while utilizing changes in gas pressure as an indicator of temperature.

By immersing this thermometer in baths of ice-water and water-steam, the pressures at the ice point (P_0) and steam point (P_{100}) are determined. The pressure interval between P_{100} and P_0 is divided into 100 equal intervals for the Celsius scale. If P_t is the pressure in a bath with a temperature (t_t) to be determined, then the relationship is expressed as:

$$t_c = \frac{P_t - P_0}{P_{100} - P_0} \times 100$$

This equation implies that the pressure (P) in the thermometer varies linearly with the measured temperature (t), resulting in a graph of P_t versus t_t forming a straight line.

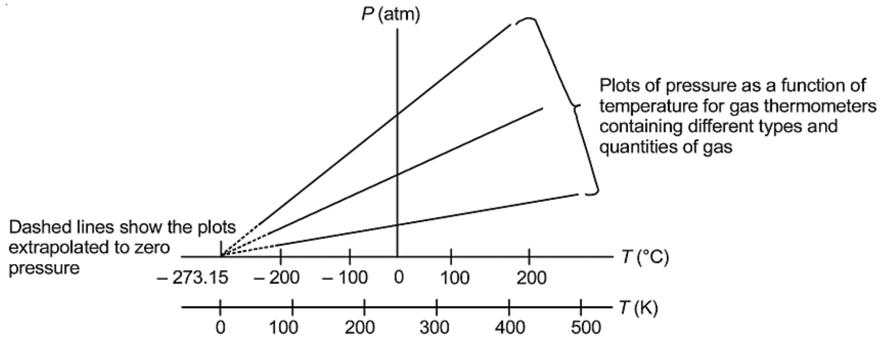


Fig.: The extrapolated plots all reach zero pressure at the same temperature – 273.15°C.

Upon extending this linear relationship to zero pressure, the temperature converges towards -273.15°C. This particular point, universally consistent across different gases, is denoted as absolute zero. An associated temperature scale established from this zero is termed the absolute temperature scale or Kelvin scale. Consequently, the relationship is expressed as:

$$0K = -273.15°C$$

The degrees or intervals on the Kelvin scale are equivalent in magnitude to those on the Celsius scale. Therefore, a temperature alteration of 1°C aligns with a change of 1 K, indicating a direct correspondence between the two scales:

$$1\ Celsius\ degree\ (C°) = 1\ kelvin\ (K)$$

The dissimilarity between the Celsius and Kelvin scales lies solely in the selection of their zero points. To convert between degrees Celsius (t_n) and kelvin (T) or vice versa, a simple addition or subtraction of 273.15 suffices:

$$T = t_n + 273.15\ or\ t_n = T - 273.15$$

Here, T symbolizes the absolute temperature.

For practical purposes, the temperature of absolute zero is commonly approximated to -273°C. In such cases, the conversion between Celsius (t_n) and Kelvin (T) is simplified to the relationship:

$T = t_n + 273$ Or $t_n = T - 273$

Presently, the triple point of water is adopted as the lower fixed point for thermometric scales. This specific temperature is standardized at 273.16 K, accompanied by a corresponding pressure of 4.58 mm of Hg. The triple point is noteworthy for its uniqueness, occurring at a specific pressure and temperature. On the Celsius and Fahrenheit scales, the triple point of water is represented as 0.01°C and 32.018°F, respectively. Thus,

$0.01°C = 32.018°F = 273.16\ K$

Conversions between degrees Fahrenheit (°F) and Kelvin (K) or vice versa are facilitated by the relation:

$$T - \frac{273.15}{100} = t_F - \frac{32}{180}$$

Which can be further expressed as:

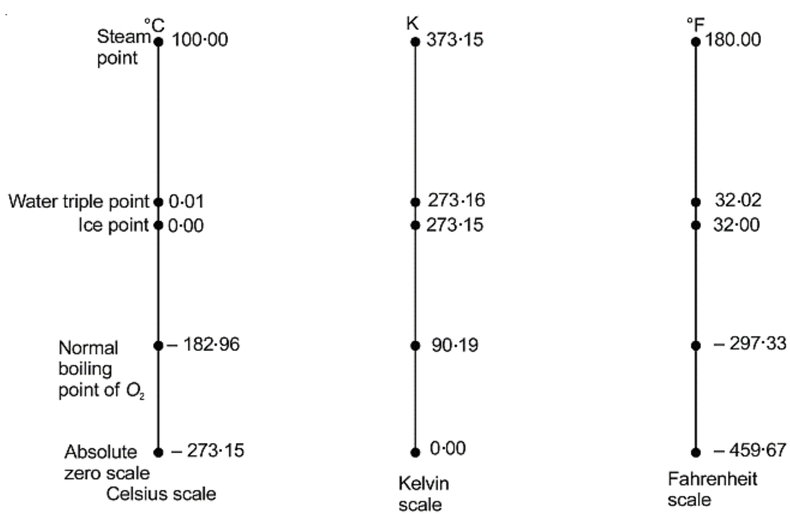
$$T = \frac{5}{9}\ (t_F - 32) + 273.15$$

Or alternatively:

$$T\ = \frac{5}{9}\ t_F - 17.78 + 273.15 = \frac{5}{9} t_F + 255.37$$

And for the conversion from Fahrenheit to Kelvin:

$$t_F = \frac{9}{5}(T - 255.37) = \frac{9}{5}T - \frac{9}{5} \times 255.37 = \frac{9}{5}\ T\ -\ 459.67$$



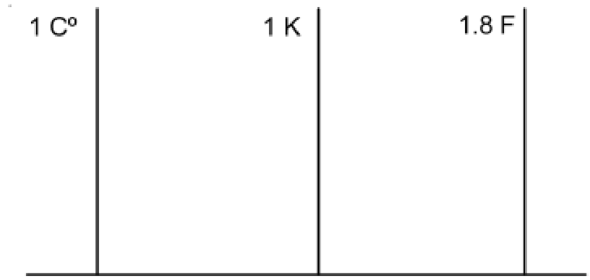


Fig.: Comparison of magnitude of change in temperature in various temperature scales

Thus, the relationships are summarized as:

$T = \frac{5}{9}\, t_F + 255.37$ Or $t_F = \frac{9}{5}\, T - 459.67$

Comparisons between Celsius, Kelvin, and Fahrenheit scales, along with the magnitudes of their units, are illustrated in the accompanying figures.

Example.

The triple points of neon and carbon dioxide manifest at temperatures of 24.57 Kelvin and 216.55 Kelvin, respectively. Requested herein is the articulation of these temperatures in both the Celsius and Fahrenheit scales.

Solution.

Given the information that the triple point of neon (T = 24.57 K) and the triple point of carbon dioxide (T = 216.55 K), let the corresponding temperatures on the Celsius and Fahrenheit scales be denoted as t_c and t_F for neon, and t_c' and t_F' for carbon dioxide, respectively.

It is evident that $t_c =$ T - 273.15, thus for neon:

$t_c = 24.57 - 273.15 = -\,248.58\ deg\ C$

Similarly, for carbon dioxide:

$t_c' = T - 273.15 = 216.55 - 273.15 = -\,56.6\ deg\ C$

Furthermore, employing the conversion relation $t_F = \frac{9}{5} \cdot t_c + 32$, the Fahrenheit temperatures are calculated as follows:

For neon:

$t_F = \frac{9}{5} \cdot (-248.58) + 32 = -447.44 + 32 = -415.44\ deg\ F$

And for carbon dioxide:

$$t'_F = \frac{9}{5} \cdot (-56.6) + 32 = 101.88 + 32 = -69.88\ deg\ F$$

Thus, the temperatures for the triple points of neon and carbon dioxide on the Celsius and Fahrenheit scales are elucidated.