THE CHEMIST'S TOOLKIT 2 Properties of bulk matter

The state of a bulk sample of matter is defined by specifying the values of various properties. Among them are:

The **mass**, m, a measure of the quantity of matter present (unit: kilogram, kg).

The **volume**, V, a measure of the quantity of space the sample occupies (unit: cubic metre, m^3).

The **amount of substance**, n, a measure of the number of specified entities (atoms, molecules, or formula units) present (unit: mole, mol).

The amount of substance, n (colloquially, 'the number of moles'), is a measure of the number of specified entities present in the sample. 'Amount of substance' is the official name of the quantity; it is commonly simplified to 'chemical amount' or simply 'amount'. A mole is currently defined as the number of carbon atoms in exactly 12 g of carbon-12. (In 2011 the decision was taken to replace this definition, but the change has not yet, in 2018, been implemented.) The number of entities per mole is called **Avogadro's constant**, N_A; the currently accepted value is $6.022 \times 10^{23}\,\text{mol}^{-1}$ (note that N_A is a constant with units, not a pure number).

The **molar mass of a substance**, M (units: formally $\text{kg}\,\text{mol}^{-1}$ but commonly $\text{g}\,\text{mol}^{-1}$) is the mass per mole of its atoms, its molecules, or its formula units. The amount of substance of specified entities in a sample can readily be calculated from its mass, by noting that

$$n = \frac{m}{M} \quad \text{Amount of substance} \quad (2.1)$$

A note on good practice Be careful to distinguish atomic or molecular mass (the mass of a single atom or molecule; unit: kg) from molar mass (the mass per mole of atoms or molecules; units: $\text{kg}\,\text{mol}^{-1}$). *Relative* molecular masses of atoms and molecules, $M_r = m/m_u$, where m is the mass of the atom or molecule and m_u is the atomic mass constant (see inside front cover of the text), are still widely called 'atomic weights' and 'molecular weights' even though they are dimensionless quantities and not weights ('weight' is the gravitational force exerted on an object).

A sample of matter may be subjected to a **pressure**, p (unit: pascal, Pa; $1\,\text{Pa} = 1\,\text{kg}\,\text{m}^{-1}\,\text{s}^{-2}$), which is defined as the force, F, it is subjected to, divided by the area, A, to which that force is applied. Although the pascal is the SI unit of pressure, it is also common to express pressure in bar ($1\,\text{bar} = 10^5\,\text{Pa}$) or atmospheres ($1\,\text{atm} = 101\,325\,\text{Pa}$ exactly), both of which correspond to typical atmospheric pressure. Because many physical properties depend on the pressure acting on a sample, it is appropriate to select a certain value of the pressure to report their values. The **standard pressure** for reporting physical quantities is currently defined as $p^{\ominus} = 1\,\text{bar}$ exactly.

To specify the state of a sample fully it is also necessary to give its **temperature**, T. The temperature is formally a property that determines in which direction energy will flow as heat when two samples are placed in contact through thermally conducting walls: energy flows from the sample with the higher temperature to the sample with the lower temperature. The symbol T is used to denote the **thermodynamic temperature** which is an absolute scale with $T = 0$ as the lowest point. Temperatures above $T = 0$ are then most commonly expressed by using the **Kelvin scale**, in which the gradations of temperature are expressed as multiples of the kelvin (K). The Kelvin scale is currently defined by setting the triple point of water (the temperature at which ice, liquid water, and water vapour are in mutual equilibrium) at exactly 273.16 K (as for certain other units, a decision has been taken to revise this definition, but it has not yet, in 2018, been implemented). The freezing point of water (the melting point of ice) at 1 atm is then found experimentally to lie 0.01 K below the triple point, so the freezing point of water is 273.15 K.

Suppose a sample is divided into smaller samples. If a property of the original sample has a value that is equal to the sum of its values in all the smaller samples (as mass would), then it is said to be **extensive**. Mass and volume are extensive properties. If a property retains the same value as in the original sample for all the smaller samples (as temperature would), then it is said to be **intensive**. In other words, the sum of the values of the smaller samples would not be equal to the value of the property of the initial sample. Temperature and pressure are intensive properties. Mass density, $\rho = m/V$, is also intensive because it would have the same value for all the smaller samples and the original sample. All molar properties, $X_m = X/n$, are intensive, whereas X and n are both extensive.