The chemist's toolkit 1 Work, pressure, and energy

When an object is moved in the x-direction for a distance x against an opposing force, F, the work done, w, is $w = Fx$. If that force is different at each point of the path (as it is when stretching a spring or a chemical bond), to calculate the work of moving between two points first calculate the infinitesimal amount of work done, dw, for movement along an infinitesimal distance, dx, at each point of the path, $\mathrm{d}w = F(x)\mathrm{d}x$ where $F(x)$ is the force at each point x, and then add together (formally: integrate) all these infinitesimal contributions from one end of the path to the other. With force in newtons ($1\,\mathrm{N} = 1\,\mathrm{kg\,m\,s^{-2}}$) and distance in metres, the units of work are joules (J), with

$$1\,\mathrm{J} = 1\,\mathrm{N\,m} = 1\,\mathrm{kg\,m^2\,s^{-2}}$$

Pressure is defined as the force exerted on a surface divided by the area of the surface:

$$P = \frac{F}{A} \qquad \text{Pressure [definition]}$$

With force in newtons and area in metres squared, pressure is reported in newtons per square metre ($\mathrm{N\,m^{-2}}$). The derived unit is the pascal (Pa):

$$1\,\mathrm{Pa} = 1\,\mathrm{N\,m^{-2}} = 1\,\mathrm{kg\,m^{-1}\,s^{-2}}$$

Pressures are often reported in bar (1 bar = 10^5 Pa) and atmospheres (1 atm = 101 325 Pa exactly).

Energy, E, is the capacity to do work, and might be stored as kinetic energy or as potential energy (or both). The SI unit of energy is the same as that of work, namely the joule. The rate of supply of energy is called the **power**, P, and is expressed in watts (W):

$$1\,\mathrm{W} = 1\,\mathrm{J\,s^{-1}}$$

The **kinetic energy**, E_k, of a body is the energy the body possesses as a result of its motion. For a body of mass m travelling at a speed v,

$$E_k = \tfrac{1}{2}mv^2 \qquad \text{Kinetic energy [definition]}$$

The **potential energy**, E_p and in some contexts V, is the energy an object possesses on account of its location. No general expression for potential energy can be given because it depends on the nature of the forces the object experiences. For an object of mass m at a height h above the surface of the Earth, the potential energy relative to its value on the surface is

$$E_p = mgh \qquad \text{Potential energy [gravitational]}$$

where g is the **acceleration of free fall**, a measure of the gravitational pull of the Earth. This quantity varies with location and altitude, but its 'standard' value at the surface of the Earth is $9.81\,\mathrm{m\,s^{-2}}$. The potential energy of an electron (of charge $-e$, typically expressed in coulombs, C) at a distance r from a nucleus of charge $+Ze$ is given by the **Coulomb potential energy**:

$$E_p = -\frac{Ze^2}{4\pi\varepsilon_0 r} \qquad \text{Coulomb potential energy [in vacuum]}$$

where ε_0 is a fundamental constant, the **electric constant**, with the value $8.854 \times 10^{-12}\,\mathrm{C^2\,m^{-1}\,J^{-1}}$. Other expressions for the potential energy are introduced at appropriate places in the text.