

Product notation: $\prod_{i=1}^n x_i = x_1 \cdot x_2 \cdot \dots \cdot x_n$
Example: $\sum_{i=1}^5 i^2$ means $1^2 + 2^2 + 3^2 + 4^2 + 5^2$
Instance: $\sum_{i=1}^3 x_i$ means $x_1 + x_2 + x_3$

Note that \sum takes all whole number values from 1 to n . So, for the sum $x_1 + x_2 + \dots + x_n$ is written $\sum_{i=1}^n x_i$.

Sigma notation: The Greek letter sigma, Σ , is used to abbreviate addition. If we have n values, x_1, x_2, \dots, x_n , and add them, $a \geq b$ means a is less than or equal to b

$a \leq b$ means a is greater than or equal to b

Inequalities: $a > b$ means a is greater than b

$\log_{10} x = \frac{\ln x}{\ln 10}$

Formula for change of base: $\log_a x = \frac{\log_b x}{\log_b a}$. Specifically, $n \log_b A = \log_b A^n$, $\log_b 1 = 0$, $\log_b b = 1$.

Laws of Logarithms: for any positive base b , with $b \neq 1$, $\log_b A + \log_b B = \log_b AB$, $\log_b A - \log_b B = \log_b \frac{A}{B}$, $\log_b A + \log_b B = \log_b AB$, $\log_b A - \log_b B = \log_b \frac{A}{B}$, $\log_b A^c = c \log_b A$

where $[H^+] =$ hydrogen ion concentration in mol dm^{-3} and $\text{pH} = -\log_{10} [H^+]$. Equivalently, $\text{pH} = -\log_{10} a_{H^+}$ where a_{H^+} is the activity of the hydrogen ion.

pH: of a solution measures its acidity or basicity. $\text{pH} = -\log_{10} [H^+]$ so $[H^+] = 10^{-\text{pH}}$

Logarithms to base 10: $\log_{10} A = c$ means $A = 10^c$. $\ln e^A = A$ if $A > 0$; $\ln(e^A) = A$

e would have to be raised to equal A . Note: c , the natural logarithm of a number A , is the power to which e would have to be raised to equal A . Note: $\log_e A = \ln A = c$ means $A = e^c$.

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Logarithms to base e , denoted \log_e or alternatively \ln are called **natural logarithms.** The letter e stands for the exponential constant which is approximately 2.718.

Laws of Indices: $a^m a^n = a^{m+n}$, $\frac{a^m}{a^n} = a^{m-n}$, $(a^m)^n = a^{mn}$, $(a^{\frac{1}{m}})^n = a^{\frac{n}{m}}$

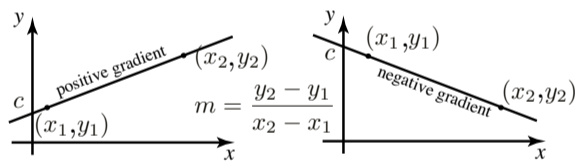
Formula for solving a quadratic equation: $ax^2 + bx + c = 0$ then $x = \frac{-b \pm \sqrt{b^2 - 4ac}}{2a}$

Removing brackets: $a(b+c) = ab+ac$, $a(b-c) = ab-ac$, $(a+b)(c+d) = ac+ad+bc+bd$, $(\frac{a}{b})^c = \frac{a^c}{b^c}$

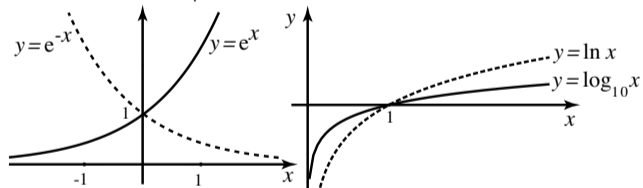
Algebra

Graphs of common functions

The straight line: $y = mx + c$.
 m = gradient (slope), c = vertical intercept.

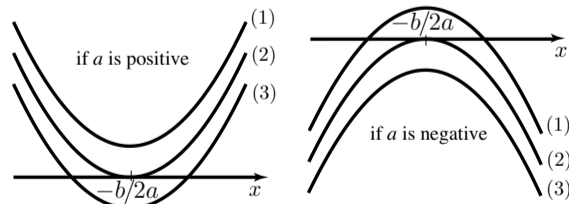


Exponential and log functions:
 $e \approx 2.718$ is the exponential constant.



Graph of $y = e^x$ and $y = e^{-x}$ showing exponential growth/decay. Graph of $y = \ln x$ and $y = \log_{10} x$

Quadratic functions: $y = ax^2 + bx + c$



- | | |
|---------------------|---------------------|
| (1) $b^2 - 4ac < 0$ | (1) $b^2 - 4ac > 0$ |
| (2) $b^2 - 4ac = 0$ | (2) $b^2 - 4ac = 0$ |
| (3) $b^2 - 4ac > 0$ | (3) $b^2 - 4ac < 0$ |

Statistics

Population values, or **parameters**, are denoted by Greek letters. Population mean = μ . Population variance = σ^2 . Population standard deviation = σ . Sample values, or **estimates**, are denoted by roman letters.

The **mean** of a sample of n observations x_1, x_2, \dots, x_n is

$$\bar{x} = \frac{\sum_{i=1}^n x_i}{n} = \frac{x_1 + x_2 + \dots + x_n}{n}$$

The sample mean \bar{x} is an unbiased estimate of the population mean μ . The unbiased estimate of the **variance** of these n sample observations is $s^2 = \frac{\sum_{i=1}^n (x_i - \bar{x})^2}{n-1}$ which can be written as

$$s^2 = \frac{1}{n-1} \sum_{i=1}^n x_i^2 - \frac{n\bar{x}^2}{n-1}$$

The sample unbiased estimate of **standard deviation**, s , is the square root of the variance: $s = \sqrt{\frac{\sum_{i=1}^n (x_i - \bar{x})^2}{n-1}}$. The standard deviation of the sample mean is called the **standard error of the mean** and is equal to $\frac{s}{\sqrt{n}}$, and is often estimated by $\frac{s}{\sqrt{n}}$.

Remember that $AB \neq BA$ except in special cases.

$$\begin{pmatrix} a & b \\ c & d \end{pmatrix} \begin{pmatrix} \alpha & \beta \\ \gamma & \delta \end{pmatrix} = \begin{pmatrix} a\alpha + b\gamma & a\beta + b\delta \\ c\alpha + d\gamma & c\beta + d\delta \end{pmatrix}$$

Matrix multiplication: for 2×2 matrices provided that $ad - bc \neq 0$.

$$\text{If } A = \begin{pmatrix} a & b \\ c & d \end{pmatrix} \text{ then } A^{-1} = \frac{1}{ad - bc} \begin{pmatrix} d & -b \\ -c & a \end{pmatrix}$$

The inverse of a 2×2 matrix:

$$|A| = \begin{vmatrix} a_{11} & a_{12} & a_{13} \\ a_{21} & a_{22} & a_{23} \\ a_{31} & a_{32} & a_{33} \end{vmatrix} = a_{11} \begin{vmatrix} a_{22} & a_{23} \\ a_{32} & a_{33} \end{vmatrix} - a_{12} \begin{vmatrix} a_{21} & a_{23} \\ a_{31} & a_{33} \end{vmatrix} + a_{13} \begin{vmatrix} a_{21} & a_{22} \\ a_{31} & a_{32} \end{vmatrix}$$

$$\text{The } 3 \times 3 \text{ matrix } A = \begin{pmatrix} a_{11} & a_{12} & a_{13} \\ a_{21} & a_{22} & a_{23} \\ a_{31} & a_{32} & a_{33} \end{pmatrix} \text{ has determinant } |A| = \begin{vmatrix} a & b \\ c & d \end{vmatrix} = ad - bc$$

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Matrices and Determinants

the reflecting planes.

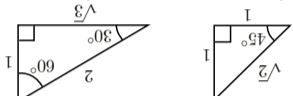
λ = wavelength of the x-rays incident on a crystal lattice with planes a distance d apart, n is an integer (whole number), and θ , the Bragg angle, is the angle between the incident beam and the reflecting planes.

Bragg's Law: a fundamental law of x-ray crystallography. $n\lambda = 2d \sin \theta$

$$\sin 60^\circ = \frac{\sqrt{3}}{2}, \cos 60^\circ = \frac{1}{2}, \tan 60^\circ = \sqrt{3}$$

$$\sin 30^\circ = \frac{1}{2}, \cos 30^\circ = \frac{\sqrt{3}}{2}, \tan 30^\circ = \frac{1}{\sqrt{3}}$$

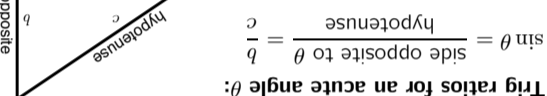
$$\sin 45^\circ = \frac{1}{\sqrt{2}}, \cos 45^\circ = \frac{1}{\sqrt{2}}, \tan 45^\circ = 1$$



Standard triangles:

$$\tan \theta = \frac{\text{side opposite to } \theta}{\text{side adjacent to } \theta} = \frac{a}{b}, \cos \theta = \frac{\text{side adjacent to } \theta}{\text{hypotenuse}} = \frac{c}{a}, \sin \theta = \frac{\text{side opposite to } \theta}{\text{hypotenuse}} = \frac{c}{b}$$

$$\text{Pythagoras' theorem: } a^2 + b^2 = c^2$$



Trig ratios for an acute angle θ :

$$1 \text{ radian} = \frac{180}{\pi} \text{ degrees} \approx 57.3^\circ$$

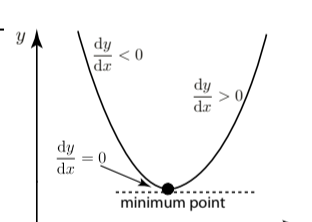
$$360^\circ = 2\pi \text{ radians}, 1^\circ = \frac{360}{2\pi} = \frac{180}{\pi} \text{ radians}$$

Trigonometry

Differentiation

Differentiating a function, $y = f(x)$, we obtain its derivative $\frac{dy}{dx}$. This new function tells us the gradient (slope) of the original function at any point. When $\frac{dy}{dx} = 0$ the gradient is zero.

$y = f(x)$	$\frac{dy}{dx} = f'(x)$
k , constant	0
x	1
x^2	$2x$
x^n , constant n	nx^{n-1}
$\sin(kx)$	$k \cos(kx)$
$\cos(kx)$	$-k \sin(kx)$
e^x	e^x
e^{kx}	ke^{kx}
$\ln kx = \log_e kx$	$\frac{1}{x}$



The linearity rules:

$$\frac{d}{dx}(u(x) \pm v(x)) = \frac{du}{dx} \pm \frac{dv}{dx}, \frac{d}{dx}(k \times f(x)) = k \times \frac{df}{dx} \text{ for } k \text{ constant.}$$

The product and quotient rules:

$$\frac{d}{dx}(uv) = u \frac{dv}{dx} + v \frac{du}{dx}, \frac{d}{dx} \left(\frac{u}{v} \right) = \frac{v \frac{du}{dx} - u \frac{dv}{dx}}{v^2}$$

The chain rule:

$$\text{If } y = y(u) \text{ where } u = u(x) \text{ then } \frac{dy}{dx} = \frac{dy}{du} \times \frac{du}{dx}$$

Higher derivatives: $f''(x)$, or $\frac{d^2 f}{dx^2}$, means differentiate $\frac{df}{dx}$ with respect to x . That is, $\frac{d^2 f}{dx^2} = \frac{d}{dx} \left(\frac{df}{dx} \right)$.

Partial derivatives: If $f = f(x, y)$ is a function of two (or more) independent variables, $\frac{\partial f}{\partial x}$ means differentiate f with respect to x treating y as if it were a constant. $\frac{\partial f}{\partial y}$ means differentiate f with respect to y treating x as if it were a constant.

Integration

$f(x)$	$\int f(x) dx$
k , constant	$kx + c$
x	$\frac{x^2}{2} + c$
x^2	$\frac{x^3}{3} + c$
x^n , ($n \neq -1$)	$\frac{x^{n+1}}{n+1} + c$
$x^{-1} = \frac{1}{x}$	$\ln x + c$ or $\ln c'x$
e^x	$e^x + c$
e^{kx}	$\frac{e^{kx}}{k} + c$
$\sin kx$	$-\frac{1}{k} \cos kx + c$
$\cos kx$	$\frac{1}{k} \sin kx + c$

The linearity rule:

$$\int (af(x) + bg(x)) dx = a \int f(x) dx + b \int g(x) dx, \quad (a, b \text{ constant})$$

$$\text{Integration by parts: } \int_a^b u \frac{dv}{dx} dx = [uv]_a^b - \int_a^b \frac{du}{dx} v dx$$

split into $\frac{m+n}{m}$ of the total and $\frac{m+n}{n}$ of the total.

Generally, to split a quantity in the ratio $m : n$, the quantity is split into $\frac{m}{m+n}$ of the total and $\frac{n}{m+n}$ of the total.

that is £120 and £80. first gets $\frac{2}{3}$ of the total, and the second gets $\frac{1}{3}$ of the total; dividing £200 between two people in the ratio of 3:2. For every £3 the first person gets, the second person gets £2. So the first gets $\frac{2}{5}$ of the total, and the second gets $\frac{3}{5}$ of the total.

Ratios are an alternative way of expressing fractions. Consider dividing £200 between two people in the ratio of 3:2. For every £3 the first person gets, the second person gets £2. So the first gets $\frac{2}{5}$ of the total, and the second gets $\frac{3}{5}$ of the total.

$$\frac{1}{10} = 10\%, \frac{1}{4} = 25\%, \frac{2}{1} = 50\%, \frac{3}{4} = 75\%$$

Some common conversions are:

$$\frac{2}{3} \text{ as a percentage is } \frac{2}{3} \times 100\% = 66.6\%$$

$$\frac{5}{8} \text{ as a percentage is } \frac{5}{8} \times 100\% = 62.5\%$$

the result as a percentage.

Proportion and Percentage: To convert a fraction to a percentage multiply by 100 and label and then multiply: e.g. $\frac{5}{3} \div \frac{2}{3} = \frac{5}{3} \times \frac{3}{2} = \frac{5}{2} = \frac{10}{4} = 250\%$

Dividing fractions: to divide two fractions, invert the second fraction and then multiply: e.g. $\frac{7}{3} \times \frac{11}{5} = \frac{7 \times 11}{3 \times 5} = \frac{77}{15}$

Multiplying fractions: to multiply two fractions, multiply their numerators and then multiply their denominators: e.g. $\frac{4}{3} \times \frac{5}{2} = \frac{4 \times 5}{3 \times 2} = \frac{20}{6} = \frac{10}{3}$

for: e.g. $\frac{5}{2} + \frac{4}{3} = \frac{15}{6} + \frac{8}{6} = \frac{23}{6}$

appropriate and the result is divided by the common denominator. Then, the numerators are added or subtracted as appropriate and the result is divided by the common denominator.

Adding and subtracting fractions: to add or subtract two fractions first rewrite each fraction so that they have the same denominator. Then, the numerators are added or subtracted as appropriate and the result is divided by the common denominator.

Fractions: fraction = $\frac{\text{numerator}}{\text{denominator}}$

OF Second priority

Division \div Second priority

Multiplication \times Second priority

Addition $+$ Third priority

Subtraction $-$ Third priority

Brackets () First priority

The BODMAS rule reminds us of the order in which operations are carried out. BODMAS stands for:

When multiplying or dividing positive and negative numbers the sign of the result is given by:

positive \times positive = positive, positive \times negative = negative, negative \times positive = negative, negative \times negative = positive

positive \div positive = positive, positive \div negative = negative, negative \div positive = negative, negative \div negative = positive

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Dalton's Law of partial pressures: states that the pressure exerted by a mix of ideal gases is the sum of the partial pressures each would exert if they were alone in the same volume:¹

$$p_{\text{total}} = p_1 + p_2 + \dots + p_n \quad \text{or} \quad p_{\text{total}} = \sum_{i=1}^n p_i$$

The partial pressure, *p*_{*i*}, of one of the gases can be calculated by multiplying the gas mole fraction, *x*_{*i*}, by the total pressure of all the gases, *p*_{total}.

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Viral equation of state: This improves the perfect gas law because it takes into account intermolecular forces.

$$pV_m = RT \left(1 + \frac{a}{V_m} + \frac{b}{V_m^2} + \dots \right)$$

*V*_{*m*} = $\frac{V}{\nu}$ = molar volume, *B*, *C* etc are the **virial coefficients**. Observe that when the molar volume is very large, the terms $\frac{a}{V_m}$ and $\frac{b}{V_m^2}$ become increasingly less important, and in the limit we obtain the ideal gas law.

Van der Waals equation takes into account the finite distance between molecules and interparticle attractions:

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Gibbs' phase rule: *F* = *C* − *P* + 2, where *F* is the number of degrees of freedom, *C* = number of independent components, *P* = the number of phases in equilibrium with each other. This is a relationship used to determine the number of state variables, *F*, chosen from amongst temperature, pressure and species compositions in each phase, which must be specified to fix the thermodynamic state of a system in equilibrium.

Clapeyron equation relates change in pressure to change in temperature at a phase boundary. The slope of the phase boundary is $\frac{dT}{dp} = \frac{L}{\Delta H}$.

Here ΔH = molar enthalpy of transition, ΔV = change in molar volume during transition.

Clausius-Clapeyron equation is an approximation of the Clapeyron equation for a liquid-vapour phase boundary. Plotting vapour pressure for various temperatures produces a curve. For pure liquids, plotting $\ln \frac{p_2}{p_1}$ against $\frac{1}{T}$ produces a straight line with gradient $-\frac{H}{R}$. (Here, *p*[∘] = any standard pressure).

$$\ln \frac{p_2}{p_1} = -\frac{H}{R} \left(\frac{1}{T_2} - \frac{1}{T_1} \right)$$

Here ΔH = molar enthalpy of vaporisation. This equation relates the natural logarithm of the vapour pressure to the temperature at a phase boundary.

Energy is often measured in calories (cal): 1 cal = 4.184 J. 1 Å = 10^{−10} m. 1 nm = 10^{−9}m. 0.1nm=100pm. **Length** (of bonds) is sometimes quoted in Ångströms, Å where 760 Torr. (1 bar = 1 × 10⁵ Pa). Then 1 atm = 1.01325 × 10⁵ Pa = 1.01325 bar = 760mm Hg = Standard atmosphere (atm). **Pressure** is often quoted in units corresponding to the between these is needed. Sometimes alternative sets of units are used and conversion **Interconversion of units:**

10 ¹²	tera	T	10 ^{−1}	deci	d
10 ⁹	giga	G	10 ^{−2}	centi	c
10 ⁶	mega	M	10 ^{−3}	milli	m
10 ³	kilo	k	10 ^{−6}	micro	μ
10 ²	hecto	h	10 ^{−9}	nano	n
10 ¹	deca	da	10 ^{−12}	pico	p

Multiple Prefix Symbol | Multiple Prefix Symbol

unit by an appropriate power of 10 to make it larger or smaller. **Common prefixes:** a prefix is a method of multiplying the SI unit by an appropriate power of 10 to make it larger or smaller.

frequency	hertz	Hz = s ^{−1}
force	newton	N = kg m s ^{−2}
pressure	pascal	Pa = N m ^{−2}
energy	joule	J = N m = kg m ² s ^{−2}
charge	coulomb	As
potential difference	volt	V = J C ^{−1}
power	watt	W = J s ^{−1}
Celsius temperature	degree Celsius	°C
Capacitance	farad	F = C V ^{−1}
Resistance	ohm	Ω

Property unit name unit symbols usually known as the newton, N.

time in the combination kg m s^{−2}. This combination is more unit of force is found by combining units of mass, length and time in the combination kg m s^{−2}. This combination is more usually known as the newton, N.

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SI base units: for most quantities it is necessary to specify the units in which they are measured.

Derived units are formed from the base units. For example, the amount of substance mole kelvin second kilogram metre SI unit Symbol

luminous intensity candela cd

current ampere A

amount of substance mole mol

temperature kelvin K

time second s

mass kilogram kg

length metre m

Quantity

Units & Conversions

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Amount of substance etc.

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Raoult's law: states that the partial vapour pressure, *p*_{*A*}, in a liquid mixture, *A*, is proportional to its mole fraction, *x*_{*A*}, and its vapour pressure when pure, *p*_{*A*}^{*}: *p*_{*A*} = *x*_{*A*}*p*_{*A*}^{*}.

Henry's law: states that the vapour pressure, *p*_{*B*}, of a volatile solute, *B*, is proportional to its mole fraction, *x*_{*B*}, in a solution: *p*_{*B*} = *x*_{*B*}*K*_{*B*}. Here *K*_{*B*} is Henry's law constant.

Chemical potential of a solvent:

$$\mu_A = \mu_A^* + RT \ln x_A$$

where μ_A^* = chemical potential of pure *A* and *x*_{*A*} is the mole fraction.

Properties of mixtures: suppose an amount *n*_{*A*} of substance *A* is mixed with *n*_{*B*} of substance *B*. The total volume of the mixture is

$$V = n_A V_{m,A} + n_B V_{m,B}$$

where *V*_{*m,A*} = partial molar volume of *A* and *V*_{*m,B*} = partial molar volume of *B*. More generally, *V* = $\sum_i n_i V_{m,i}$, where *V*_{*m,i*} is the partial molar volume of the *i*th substance.

Total Gibbs energy for the mixture is *G* = *n*_{*A*} *G*_{*A*} + *n*_{*B*} *G*_{*B*} where *G*_{*A*} and *G*_{*B*} are the **partial molar Gibbs energies** of substances *A* and *B* respectively. The partial molar Gibbs energies are also denoted μ_A and μ_B so that *G* = *n*_{*A*} μ_A + *n*_{*B*} μ_B . More generally, with mixtures of several substances *G* = $\sum_i n_i \mu_i$.

Reaction Thermodynamics

Standard state: The standard state of a substance is the pure substance at a pressure of 1 bar. The standard state value is denoted by the superscript symbol [∘], as in *G*[∘].

Reaction Gibbs energy: $\Delta_r G = \frac{\Delta G}{\Delta \xi}$ is the slope of the graph of Gibbs energy against the progress of the reaction. Here, $\Delta \xi = \Delta n_J / \nu_J$ for all species *J* in the reaction. Reaction Gibbs energy at any composition of the reaction mixture can be written

$$\Delta_r G = \Delta_r G^\ominus + RT \ln Q \quad \text{where } Q = \prod_{\text{J}} a_{\text{J}}^{\nu_{\text{J}}}$$

where *a*_{*J*} is the activity of species *J* and ν_J is its stoichiometric number.

At equilibrium *Q* = *K*, $\Delta_r G$ = 0 and $-\Delta_r G^\ominus = RT \ln K$ where

$$K = \prod_{\text{J}} (a_{\text{J}}^{\nu_{\text{J}}})_{\text{equilibrium}}$$

van't Hoff equation: $\frac{d}{dT} \ln K = \frac{\Delta_r H^\ominus}{RT^2}$.

$$\ln \left(\frac{K_2}{K_1} \right) = -\frac{\Delta_r H^\ominus}{R} \left[\frac{1}{T_2} - \frac{1}{T_1} \right]$$

The mole is the amount of substance that contains 6.0221415 × 10²³ (Avogadro constant/mol^{−1}) atoms or molecules of the pure substance being measured. For example 1 mole (mol) of potassium will contain *N*_A atoms. 1 mole of water contains *N*_A water molecules. A mole of any substance contains as many atoms or molecules (as specified) as there are atoms in 12g of the carbon isotope ¹²C. (To avoid confusion, always specify the type of particle.)

The molar mass, *M*, of a substance is the mass divided by chemical amount. For pure materials, molar mass, *M* = molar weight (or relative atomic or molecular mass) × g mol^{−1}. The **concentration** or **molarity** of a solute is *c* = $\frac{n}{V}$ where *n* = amount of solute, *V* = volume of solution. Molarity is usually quoted in mol dm^{−3}. The unit 1 mol dm^{−3} is commonly denoted 1 M and read as 'molar'.

The **molarity**, *b*, of a solute is the amount of solute divided by the mass of solvent: *b* = $\frac{m}{m}$. So, molarity represents 1 mole of a solute in 1 kg of solvent.

The **mole fraction**, *x*, of a solute is the amount of solute divided by the total amount in the solution:

$$x = \frac{n_{\text{solute}}}{n_{\text{total}}}$$

The **mass density** (or just **density**), *ρ*, of a substance is its mass divided by its volume, that is *ρ* = $\frac{M}{V}$.

The **mass percentage** is the mass of a substance in a mixture as a percentage of the total mass of the mixture.

The **mass-volume percentage** is the number of grams of solute in 100 millilitres of solution.

The **volume-volume percentage** is the number of millilitres of liquid solute in 100 millilitres of solution.

Parts per million (ppm): mg/kg.

Parts per billion (ppb): $\frac{\text{Mass obtained}}{\text{theoretical yield}} \times 100$

Gases

The general form of an **equation of state** is *p* = *f*(*T*,*V*,*n*) where *p* = pressure, *T* is temperature, *V* = volume, *n* = amount of substance.

Boyle's Law relates the pressure and volume of a gas when the temperature is fixed: *p*1*V*1 = *p*2*V*2.

An equivalent form is: *pV* = $\frac{3}{2}nM\overline{c^2}$, where *n* = number of molecules, *m* = mass of a molecule, *M* (= *mN*_A) is the molar mass of the molecules, $\overline{c^2}$ = mean square speed.

Charles's Law relates the volume and temperature of a gas at constant pressure: $\frac{V_2}{V_1} = \frac{T_2}{T_1}$.

Amount of substance etc.

Dalton's Law of partial pressures: states that the pressure exerted by a mix of ideal gases is the sum of the partial pressures each would exert if they were alone in the same volume:¹

$$p_{\text{total}} = p_1 + p_2 + \dots + p_n \quad \text{or} \quad p_{\text{total}} = \sum_{i=1}^n p_i$$

The partial pressure, *p*_{*i*}, of one of the gases can be calculated by multiplying the gas mole fraction, *x*_{*i*}, by the total pressure of all the gases, *p*_{total}.

Perfect Gas Law: *pV* = *nRT* where *H* = ideal gas constant.

Combined Gas Laws: $\frac{p_1 V_1}{p_2 V_2} = \frac{nRT_1}{nRT_2}$.

Viral equation of state: This improves the perfect gas law because it takes into account intermolecular forces.

$$pV_m = RT \left(1 + \frac{a}{V_m} + \frac{b}{V_m^2} + \dots \right)$$

*V*_{*m*} = $\frac{V}{\nu}$ = molar volume, *B*, *C* etc are the **virial coefficients**. Observe that when the molar volume is very large, the terms $\frac{a}{V_m}$ and $\frac{b}{V_m^2}$ become increasingly less important, and in the limit we obtain the ideal gas law.

Van der Waals equation takes into account the finite distance between molecules and interparticle attractions:

$$\left(p + \frac{a}{V_m^2} \right) (V_m - b) = nRT$$

a is a measure of attraction between particles, *b* is the volume excluded by a mole of particles.

Gibbs' phase rule: *F* = *C* − *P* + 2, where *F* is the number of degrees of freedom, *C* = number of independent components, *P* = the number of phases in equilibrium with each other. This is a relationship used to determine the number of state variables, *F*, chosen from amongst temperature, pressure and species compositions in each phase, which must be specified to fix the thermodynamic state of a system in equilibrium.

Clapeyron equation relates change in pressure to change in temperature at a phase boundary. The slope of the phase boundary is $\frac{dT}{dp} = \frac{L}{\Delta H}$.

Here ΔH = molar enthalpy of transition, ΔV = change in molar volume during transition.

Clausius-Clapeyron equation is an approximation of the Clapeyron equation for a liquid-vapour phase boundary. Plotting vapour pressure for various temperatures produces a curve. For pure liquids, plotting $\ln \frac{p_2}{p_1}$ against $\frac{1}{T}$ produces a straight line with gradient $-\frac{H}{R}$. (Here, *p*[∘] = any standard pressure).

$$\ln \frac{p_2}{p_1} = -\frac{H}{R} \left(\frac{1}{T_2} - \frac{1}{T_1} \right)$$

Here ΔH = molar enthalpy of vaporisation. This equation relates the natural logarithm of the vapour pressure to the temperature at a phase boundary.

Energy is often measured in calories (cal): 1 cal = 4.184 J. 1 Å = 10^{−10} m. 1 nm = 10^{−9}m. 0.1nm=100pm. **Length** (of bonds) is sometimes quoted in Ångströms, Å where 760 Torr. (1 bar = 1 × 10⁵ Pa). Then 1 atm = 1.01325 × 10⁵ Pa = 1.01325 bar = 760mm Hg = Standard atmosphere (atm). **Pressure** is often quoted in units corresponding to the between these is needed. Sometimes alternative sets of units are used and conversion **Interconversion of units:**

10 ¹²	tera	T	10 ^{−1}	deci	d
10 ⁹	giga	G	10 ^{−2}	centi	c
10 ⁶	mega	M	10 ^{−3}	milli	m
10 ³	kilo	k	10 ^{−6}	micro	μ
10 ²	hecto	h	10 ^{−9}	nano	n
10 ¹	deca	da	10 ^{−12}	pico	p

Multiple Prefix Symbol | Multiple Prefix Symbol

unit by an appropriate power of 10 to make it larger or smaller. **Common prefixes:** a prefix is a method of multiplying the SI unit by an appropriate power of 10 to make it larger or smaller.

frequency	hertz	Hz = s ^{−1}
force	newton	N = kg m s ^{−2}
pressure	pascal	Pa = N m ^{−2}
energy	joule	J = N m = kg m ² s ^{−2}
charge	coulomb	As
potential difference	volt	V = J C ^{−1}
power	watt	W = J s ^{−1}
Celsius temperature	degree Celsius	°C
Capacitance	farad	F = C V ^{−1}
Resistance	ohm	Ω

Property unit name unit symbols usually known as the newton, N.

time in the combination kg m s^{−2}. This combination is more unit of force is found by combining units of mass, length and time in the combination kg m s^{−2}. This combination is more usually known as the newton, N.

Units & Conversions

The Greek alphabet

<i>A</i>	<i>α</i>	alpha	<i>I</i>	<i>ι</i>	iota	<i>P</i>	<i>ρ</i>	rho
<i>B</i>	<i>β</i>	beta	<i>K</i>	<i>κ</i>	kappa	<i>Σ</i>	<i>σ</i>	sigma
<i>Γ</i>	<i>γ</i>	gamma	<i>Λ</i>	<i>λ</i>	lambda	<i>T</i>	<i>τ</i>	tau
<i>Δ</i>	<i>δ</i>	delta	<i>M</i>	<i>μ</i>	mu	<i>Υ</i>	<i>υ</i>	upsilon
<i>E</i>	<i>ε</i>	epsilon	<i>N</i>	<i>ν</i>	nu	<i>Φ</i>	<i>φ</i>	phi
<i>Z</i>	<i>ζ</i>	zeta	<i>Ξ</i>	<i>ξ</i>	xi	<i>X</i>	<i>χ</i>	chi
<i>H</i>	<i>η</i>	eta	<i>O</i>	<i>ο</i>	omicron	<i>Ψ</i>	<i>ψ</i>	psi
<i>Θ</i>	<i>θ</i>	theta	<i>Π</i>	<i>π</i>	pi	<i>Ω</i>	<i>ω</i>	omega

Scalars product:

a · b = |a| |b| cos θ

If **a** = *a*₁**i** + *a*₂**j** + *a*₃**k** and **b** = *b*₁**i** + *b*₂**j** + *b*₃**k** then

$$\mathbf{a} \cdot \mathbf{b} = a_1 b_1 + a_2 b_2 + a_3 b_3$$

Vector product:

a × b = |a| |b| sin θ ê

ê is a unit vector perpendicular to the plane containing **a** and **b** in a sense defined by the right hand screw rule.

If **a** = *a*₁**i** + *a*₂**j** + *a*₃**k** and **b** = *b*₁**i** + *b*₂**j** + *b*₃**k** then

$$\mathbf{a} \times \mathbf{b} = (a_2 b_3 - a_3 b_2)\mathbf{i} + (a_3 b_1 - a_1 b_3)\mathbf{j} + (a_1 b_2 - a_2 b_1)\mathbf{k}$$

$$= \begin{vmatrix} \mathbf{i} & \mathbf{j} & \mathbf{k} \\ a_1 & a_2 & a_3 \\ b_1 & b_2 & b_3 \end{vmatrix}$$

Kinetics

Arrhenius equation: The **rate** at which most chemical reactions proceed depends upon the **temperature**. The amount of energy necessary for the reaction to take place at all is called the **activation energy**. These quantities are related by the Arrhenius equation: *k* = Ae^{−*E*_a/(*RT*)}

where *k* = rate constant, *E*_{*a*} = the activation energy for the reaction, *R* = ideal gas constant, *T* = absolute temperature, and *A* is a constant.

By taking logarithms this can be expressed as

$$\ln \frac{k}{k^\ominus} = \ln \frac{A}{k^\ominus} - \frac{E_a}{RT}$$

where *k*[∘] is a chosen standard rate constant. Together, *A* and *E*_{*a*} are called the **Arrhenius parameters**.

Rate Laws

In the table, [A] = molar concentration of reactant *A* at time *t*. [A]₀ = concentration of reactant *A* at time *t* = 0.

Order	Rate Law Differential form	Rate Law Integrated form	Half-life	Common unit of <i>k</i>
0	$\frac{d[A]}{dt} = -k$	<i>[A]</i> ₀ − <i>[A]</i> = <i>kt</i>	$\frac{[A]_0}{2k}$	mol dm ^{−3} s ^{−1}
1	$\frac{d[A]}{dt} = -k[A]$	<i>[A]</i> = <i>[A]</i> ₀ e ^{−<i>kt</i>}	$\frac{\ln 2}{k}$	s ^{−1}
2	$\frac{d[A]}{dt} = -k[A]^2$	$\frac{1}{[A]} - \frac{1}{[A]_0} = kt$	$\frac{1}{k[A]_0}$	mol ^{−1} dm ³ s ^{−1}
2*	$\frac{d[A]}{dt} = -k[A][B]$	$\frac{1}{[B]_0 - [A]_0} \ln \frac{[B][A]_0}{[A][B]_0} = kt$	-	mol ^{−1} dm ³ s ^{−1}

^{[*] A + B → P reaction.)}

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