# Formulas

| Processing of data |
| --- |
| Absolute uncertainty of the mean $\Delta\bar{x} = \pm\frac{(x_{\max} - x_{\min})}{2}$ |
| Percentage uncertainty (%) $= \frac{\text{absolute uncertainty}}{\text{measurement}} \times \frac{100}{1}$ |
| Percentage error (%) $= \left\lvert\frac{\text{measured value} - \text{true value}}{\text{true value}}\right\rvert \times 100$ |

| Chemical reactions — reactants, products and energy change |
| --- |
| $\triangle H = H_{\text{(products)}} - H_{\text{(reactants)}}$ |
| $\triangle H = \Sigma$(bonds broken) – $\Sigma$(bonds formed) |
| $Q = mc\Delta T$ |
| Percentage yield (%) $= \frac{\text{experimental yield}}{\text{theoretical yield}} \times \frac{100}{1}$ |

| Aqueous solutions and acidity |
| --- |
| Molarity $= \frac{\text{moles of solute } (n)}{\text{volume of solution } (V)}$ |

| Chemical equilibrium systems |
| --- |
| $K_c = \frac{[C]^c}{[A]^a}\frac{[D]^d}{[B]^b}$ for the reaction: aA + bB ⇌ cC + dD |
| $K_w = [H^+][OH^-]$ |
| $pH = -\log_{10}[H^+]$ |
| $pOH = -\log_{10}[OH^-]$ |
| $K_w = K_a \times K_b$ |
| $K_a = \frac{[H_3O^+][A^-]}{[HA]}$ |
| $K_b = \frac{[BH^+][OH^-]}{[B]}$ |

# Physical constants and unit conversions

| Physical constants and unit conversions | |
|---|---|
| Absolute zero | 0 K = –273 °C |
| Atomic mass unit | 1 amu = $1.66 \times 10^{-27}$ kg |
| Avogadro's constant | $N_A = 6.02 \times 10^{23}$ mol$^{-1}$ |
| Ideal gas constant | $R = 8.31$ J mol$^{-1}$ K$^{-1}$ |
| Ionic product constant for water (at 298 K) | $K_w = 1.00 \times 10^{-14}$ mol$^2$ dm$^{-6}$ |
| Molar volume of an ideal gas (at STP) | $2.27 \times 10^{-2}$ m$^3$ mol$^{-1}$ = 22.7 dm$^3$ mol$^{-1}$ |
| Specific heat capacity of water (at 298 K) | $c_w = 4.18$ J g$^{-1}$ K$^{-1}$ |
| Standard temperature and pressure (STP) | 273 K and 100 kPa |
| Volume and capacity conversions | 1 dm$^3$ = $1 \times 10^{-3}$ m$^3$ = $1 \times 10^3$ cm$^3$ = 1 L |

# List of elements

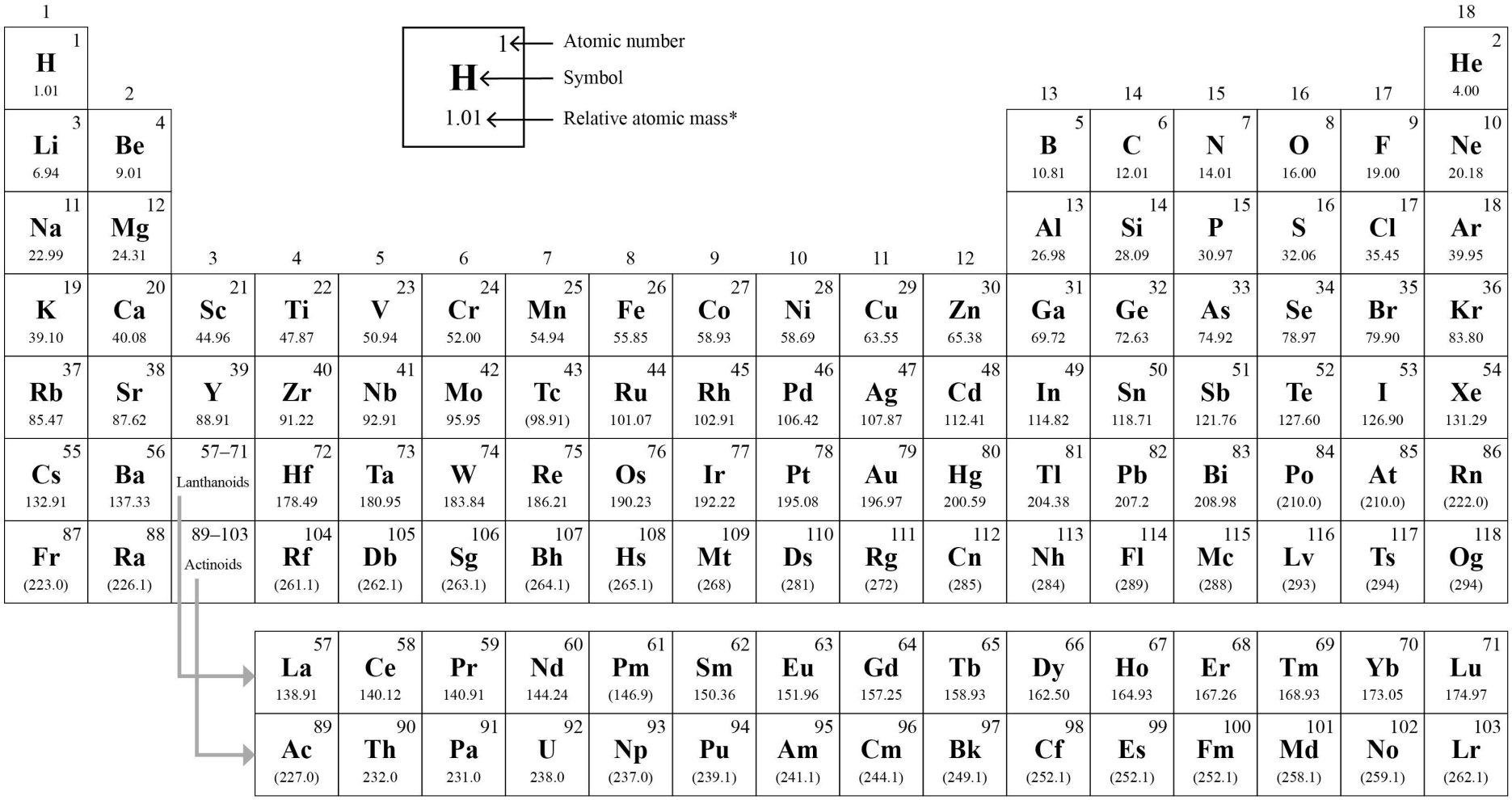
| Name | Atomic no. | Symbol |
|---|---|---|
| Hydrogen | 1 | H |
| Helium | 2 | He |
| Lithium | 3 | Li |
| Beryllium | 4 | Be |
| Boron | 5 | B |
| Carbon | 6 | C |
| Nitrogen | 7 | N |
| Oxygen | 8 | O |
| Fluorine | 9 | F |
| Neon | 10 | Ne |
| Sodium | 11 | Na |
| Magnesium | 12 | Mg |
| Aluminium | 13 | Al |
| Silicon | 14 | Si |
| Phosphorus | 15 | P |
| Sulfur | 16 | S |
| Chlorine | 17 | Cl |
| Argon | 18 | Ar |
| Potassium | 19 | K |
| Calcium | 20 | Ca |
| Scandium | 21 | Sc |
| Titanium | 22 | Ti |
| Vanadium | 23 | V |
| Chromium | 24 | Cr |
| Manganese | 25 | Mn |
| Iron | 26 | Fe |
| Cobalt | 27 | Co |
| Nickel | 28 | Ni |
| Copper | 29 | Cu |
| Zinc | 30 | Zn |

| Name | Atomic no. | Symbol |
|---|---|---|
| Gallium | 31 | Ga |
| Germanium | 32 | Ge |
| Arsenic | 33 | As |
| Selenium | 34 | Se |
| Bromine | 35 | Br |
| Krypton | 36 | Kr |
| Rubidium | 37 | Rb |
| Strontium | 38 | Sr |
| Yttrium | 39 | Y |
| Zirconium | 40 | Zr |
| Niobium | 41 | Nb |
| Molybdenum | 42 | Mo |
| Technetium | 43 | Tc |
| Ruthenium | 44 | Ru |
| Rhodium | 45 | Rh |
| Palladium | 46 | Pd |
| Silver | 47 | Ag |
| Cadmium | 48 | Cd |
| Indium | 49 | In |
| Tin | 50 | Sn |
| Antimony | 51 | Sb |
| Tellurium | 52 | Te |
| Iodine | 53 | I |
| Xenon | 54 | Xe |
| Cesium | 55 | Cs |
| Barium | 56 | Ba |
| Lanthanum | 57 | La |
| Cerium | 58 | Ce |
| Praseodymium | 59 | Pr |
| Neodymium | 60 | Nd |

| Name | Atomic no. | Symbol |
|---|---|---|
| Promethium | 61 | Pm |
| Samarium | 62 | Sm |
| Europium | 63 | Eu |
| Gadolinium | 64 | Gd |
| Terbium | 65 | Tb |
| Dysprosium | 66 | Dy |
| Holmium | 67 | Ho |
| Erbium | 68 | Er |
| Thulium | 69 | Tm |
| Ytterbium | 70 | Yb |
| Lutetium | 71 | Lu |
| Hafnium | 72 | Hf |
| Tantalum | 73 | Ta |
| Tungsten | 74 | W |
| Rhenium | 75 | Re |
| Osmium | 76 | Os |
| Iridium | 77 | Ir |
| Platinum | 78 | Pt |
| Gold | 79 | Au |
| Mercury | 80 | Hg |
| Thallium | 81 | Tl |
| Lead | 82 | Pb |
| Bismuth | 83 | Bi |
| Polonium | 84 | Po |
| Astatine | 85 | At |
| Radon | 86 | Rn |
| Francium | 87 | Fr |
| Radium | 88 | Ra |
| Actinium | 89 | Ac |
| Thorium | 90 | Th |

| Name | Atomic no. | Symbol |
|---|---|---|
| Protactinium | 91 | Pa |
| Uranium | 92 | U |
| Neptunium | 93 | Np |
| Plutonium | 94 | Pu |
| Americium | 95 | Am |
| Curium | 96 | Cm |
| Berkelium | 97 | Bk |
| Californium | 98 | Cf |
| Einsteinium | 99 | Es |
| Fermium | 100 | Fm |
| Mendelevium | 101 | Md |
| Nobelium | 102 | No |
| Lawrencium | 103 | Lr |
| Rutherfordium | 104 | Rf |
| Dubnium | 105 | Db |
| Seaborgium | 106 | Sg |
| Bohrium | 107 | Bh |
| Hassium | 108 | Hs |
| Meitnerium | 109 | Mt |
| Darmstadtium | 110 | Ds |
| Roentgenium | 111 | Rg |
| Copernicium | 112 | Cn |
| Nihonium | 113 | Nh |
| Flerovium | 114 | Fl |
| Moscovium | 115 | Mc |
| Livermorium | 116 | Lv |
| Tennessine | 117 | Ts |
| Oganesson | 118 | Og |

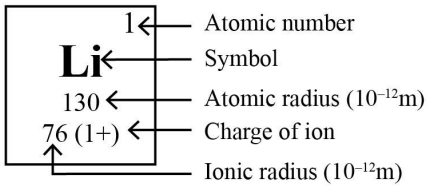
# Periodic table of the elements




Groups are numbered according to IUPAC convention 1–18.

*Values in brackets are for the isotope with the longest half-life.

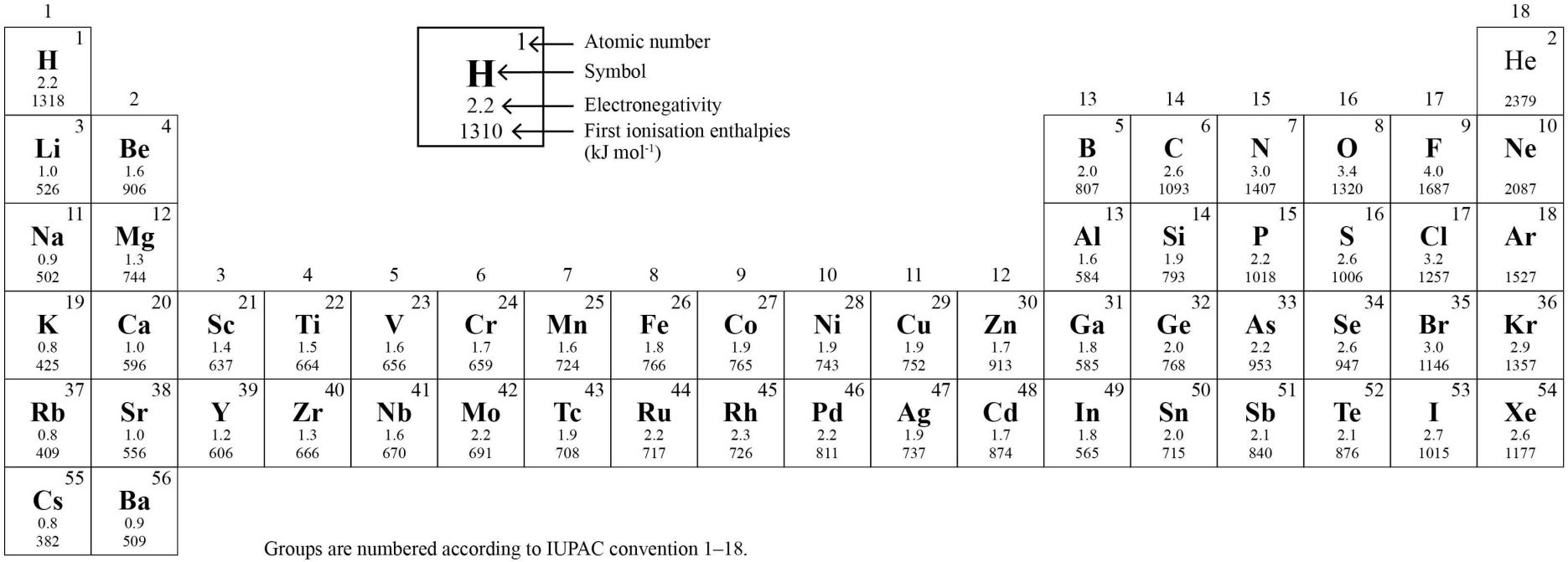
# Atomic and ionic radii of selected elements




| 1 | | | | | | | | | | | | | | | | | 18 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1 **H** 32 208 (1−) | 2 | | | | | | | | | | | 13 | 14 | 15 | 16 | 17 | 2 **He** 37 |
| 3 **Li** 130 76 (1+) | 4 **Be** 99 45 (2+) | | | | | | | | | | | 5 **B** 84 27 (3+) | 6 **C** 75 16 (4+) | 7 **N** 71 146 (3−) | 8 **O** 64 140 (2−) | 9 **F** 60 133 (1−) | 10 **Ne** 62 |
| 11 **Na** 160 102 (1+) | 12 **Mg** 140 72 (2+) | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 | 13 **Al** 124 53 (3+) | 14 **Si** 114 40 (4+) | 15 **P** 109 38 (5+) | 16 **S** 104 184 (2−) | 17 **Cl** 100 181 (1−) | 18 **Ar** 101 |
| 19 **K** 200 138 (1+) | 20 **Ca** 174 100 (2+) | 21 **Sc** 159 75 (3+) | 22 **Ti** 148 86 (2+) 61 (4+) | 23 **V** 144 79 (2+) 54 (5+) | 24 **Cr** 130 62 (3+) 44 (6+) | 25 **Mn** 129 83 (2+) 64 (3+) | 26 **Fe** 124 78 (2+) 64 (3+) | 27 **Co** 118 74 (2+) 61 (3+) | 28 **Ni** 117 69 (2+) 60 (3+) | 29 **Cu** 122 77 (1+) 73 (2+) | 30 **Zn** 120 74 (2+) | 31 **Ga** 123 62 (3+) | 32 **Ge** 120 53 (4+) 272 (4−) | 33 **As** 120 58 (3+) 46 (5+) | 34 **Se** 118 198 (2−) | 35 **Br** 117 196 (1−) | 36 **Kr** 116 |
| 37 **Rb** 215 152 (1+) | 38 **Sr** 190 118 (2+) | 39 **Y** 176 90 (3+) | 40 **Zr** 164 72 (4+) | 41 **Nb** 156 64 (5+) | 42 **Mo** 148 65 (4+) | 43 **Tc** 138 65 (4+) | 44 **Ru** 136 62 (4+) | 45 **Rh** 134 67 (3+) | 46 **Pd** 130 86 (2+) | 47 **Ag** 136 115 (1+) | 48 **Cd** 140 95 (2+) | 49 **In** 142 80 (3+) | 50 **Sn** 140 69 (4+) | 51 **Sb** 140 76 (3+) | 52 **Te** 137 221 (2−) | 53 **I** 136 220 (1−) | 54 **Xe** 136 |
| 55 **Cs** 238 167 (1+) | 56 **Ba** 206 135 (2+) | | | | | | | | | | | | | | | | |

Groups are numbered according to IUPAC convention 1–18.

# Electronegativities and first ionisation energies of selected elements




Groups are numbered according to IUPAC convention 1–18.

# Solubility of selected compounds at 298 K

| | bromide | carbonate | chloride | hydroxide | iodide | nitrate | oxide | phosphate | sulfate |
|---|---|---|---|---|---|---|---|---|---|
| **aluminium** | s | – | s | i | s | s | i | i | s |
| **ammonium** | s | s | s | s | s | s | – | s | s |
| **barium** | s | i | s | s | s | s | s | i | i |
| **calcium** | s | i | s | p | s | s | p | i | p |
| **cobalt(II)** | s | i | s | i | s | s | i | i | s |
| **copper(II)** | s | – | s | i | i | s | i | i | s |
| **iron(II)** | s | i | s | i | s | s | i | i | s |
| **iron(III)** | s | – | s | i | s | s | i | i | s |
| **lead(II)** | p | i | s | i | i | s | i | i | i |
| **lithium** | s | s | s | s | s | s | s | – | s |
| **magnesium** | s | i | s | i | s | s | i | p | s |
| **manganese(II)** | s | i | s | i | s | s | i | p | s |
| **potassium** | s | s | s | s | s | s | s | s | s |
| **silver** | i | i | i | i | i | s | i | i | p |
| **sodium** | s | s | s | s | s | s | s | s | s |
| **zinc** | s | i | s | i | s | s | i | i | s |

## Key:

| Abbreviation | explanation |
|---|---|
| s | soluble in water (solubility greater than 10 g $L^{-1}$) |
| p | partially soluble in water (solubility between 1 and 10 g $L^{-1}$) |
| i | insoluble in water (solubility less than 1 g $L^{-1}$) |
| – | no data |

# Average bond enthalpies at 298 K

## Single bonds

| | $\Delta H$ (kJ mol$^{-1}$) | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | **H** | **C** | **N** | **O** | **F** | **S** | **Cl** | **Br** | **I** |
| **H** | 436 | | | | | | | | |
| **C** | 414 | 346 | | | | | | | |
| **N** | 391 | 286 | 158 | | | | | | |
| **O** | 463 | 358 | 214 | 144 | | | | | |
| **F** | 567 | 492 | 278 | 191 | 159 | | | | |
| **S** | 364 | 289 | | | 327 | 266 | | | |
| **Cl** | 431 | 324 | 192 | 206 | 255 | 271 | 242 | | |
| **Br** | 366 | 285 | | 201 | 249 | 218 | 219 | 193 | |
| **I** | 298 | 228 | | 201 | 280 | | 211 | 178 | 151 |

## Multiple bonds

| **Bond** | **ΔH (kJ mol$^{-1}$)** |
|---|---|
| C=C | 614 |
| C≡C | 839 |
| C=N | 615 |
| C≡N | 890 |
| C=O | 804 |
| N=N | 470 |
| N≡N | 945 |
| O=O | 498 |

# Reactivity series of metals

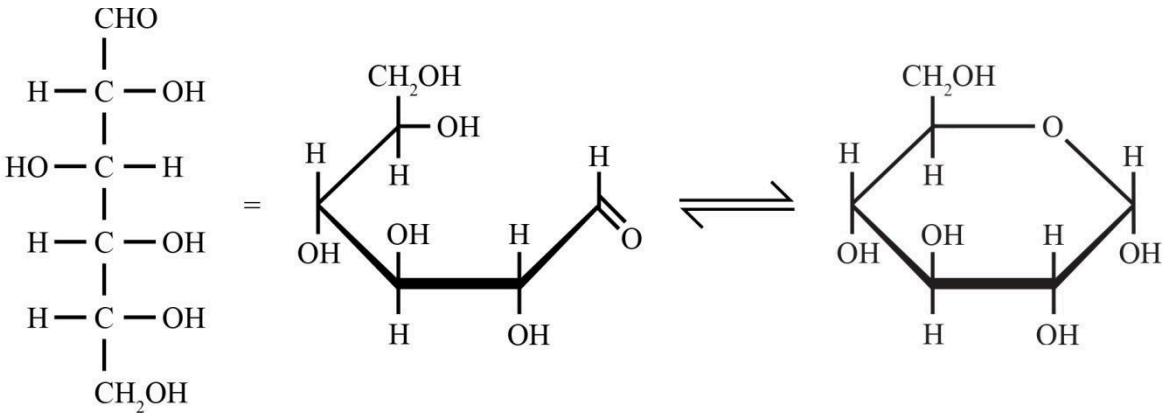
| Element | Reactivity |
|---|---|
| K | most reactive |
| Na | |
| Li | |
| Ba | |
| Sr | |
| Ca | |
| Mg | |
| Al | |
| C* | |
| Mn | |
| Zn | |
| Cr | |
| Fe | |
| Cd | |
| Co | |
| Ni | |
| Sn | |
| Pb | |
| $H_2$* | |
| Sb | |
| Bi | |
| Cu | |
| Hg | |
| Ag | |
| Au | |
| Pt | least reactive |

* Carbon (C) and hydrogen gas ($H_2$) added for comparison

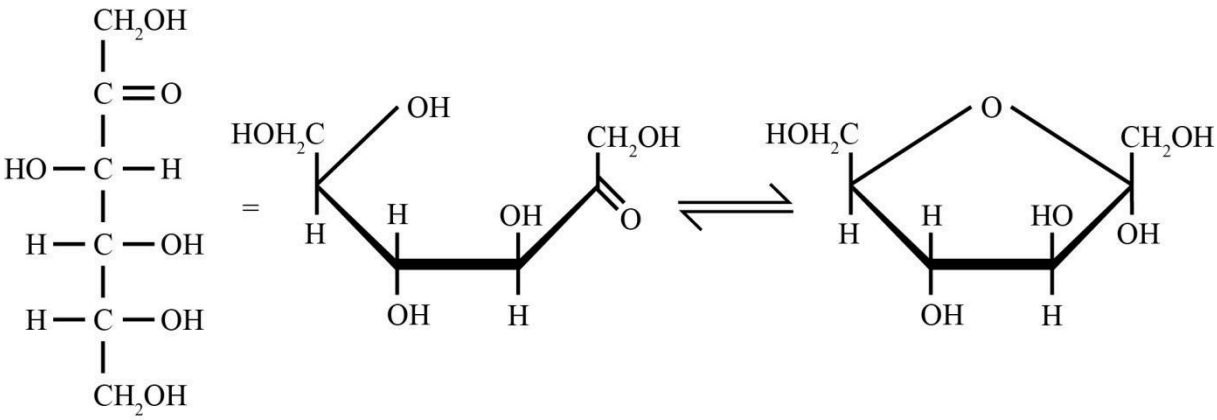
# Standard electrode potentials at 298 K

| Oxidised species ⇌ Reduced species | $E^\circ$ (V) |
|---|---|
| $Li^+(aq) + e^- \rightleftharpoons Li(s)$ | –3.04 |
| $K^+(aq) + e^- \rightleftharpoons K(s)$ | –2.94 |
| $Ba^{2+}(aq) + 2e^- \rightleftharpoons Ba(s)$ | –2.91 |
| $Ca^{2+}(aq) + 2e^- \rightleftharpoons Ca(s)$ | –2.87 |
| $Na^+(aq) + e^- \rightleftharpoons Na(s)$ | –2.71 |
| $Mg^{2+}(aq) + 2e^- \rightleftharpoons Mg(s)$ | –2.36 |
| $Al^{3+}(aq) + 3e^- \rightleftharpoons Al(s)$ | –1.68 |
| $Mn^{2+}(aq) + 2e^- \rightleftharpoons Mn(s)$ | –1.18 |
| $2H_2O(l) + 2e^- \rightleftharpoons H_2(g) + 2OH^-(aq)$ | –0.83 |
| $Zn^{2+}(aq) + 2e^- \rightleftharpoons Zn(s)$ | –0.76 |
| $Fe^{2+}(aq) + 2e^- \rightleftharpoons Fe(s)$ | –0.44 |
| $Ni^{2+}(aq) + 2e^- \rightleftharpoons Ni(s)$ | –0.24 |
| $Sn^{2+}(aq) + 2e^- \rightleftharpoons Sn(s)$ | –0.14 |
| $Pb^{2+}(aq) + 2e^- \rightleftharpoons Pb(s)$ | –0.13 |
| $2H^+(aq) + 2e^- \rightleftharpoons H_2(g)$ | 0.00 |
| $Cu^{2+}(aq) + e^- \rightleftharpoons Cu^+(aq)$ | +0.16 |
| $SO_4^{2-}(aq) + 4H^+(aq) + 2e^- \rightleftharpoons SO_2(aq) + 2H_2O(l)$ | +0.16 |
| $Cu^{2+}(aq) + 2e^- \rightleftharpoons Cu(s)$ | +0.34 |
| $O_2(g) + 2H_2O(l) + 4e^- \rightleftharpoons 4OH^-(aq)$ | +0.40 |
| $Cu^+(aq) + e^- \rightleftharpoons Cu(s)$ | +0.52 |
| $I_2(s) + 2e^- \rightleftharpoons 2I^-(aq)$ | +0.54 |
| $Fe^{3+}(aq) + e^- \rightleftharpoons Fe^{2+}(aq)$ | +0.77 |
| $Ag^+(aq) + e^- \rightleftharpoons Ag(s)$ | +0.80 |
| $Br_2(l) + 2e^- \rightleftharpoons 2Br^-(aq)$ | +1.08 |
| $O_2(g) + 4H^+(aq) + 4e^- \rightleftharpoons 2H_2O(l)$ | +1.23 |
| $Cl_2(g) + 2e^- \rightleftharpoons 2Cl^-(aq)$ | +1.36 |
| $Cr_2O_7^{2-}(aq) + 14H^+(aq) + 6e^- \rightleftharpoons 2Cr^{3+}(aq) + 7H_2O(l)$ | +1.36 |
| $MnO_4^-(aq) + 8H^+(aq) + 5e^- \rightleftharpoons Mn^{2+}(aq) + 4H_2O(l)$ | +1.51 |
| $F_2(g) + 2e^- \rightleftharpoons 2F^-(aq)$ | +2.89 |

# Glucose and fructose: straight chain and *α*-ring forms

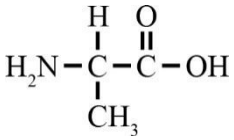
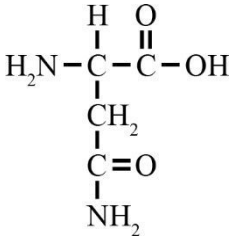
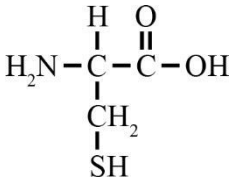
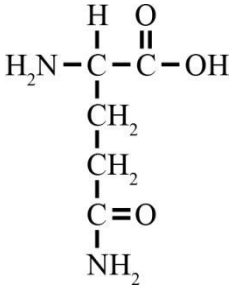
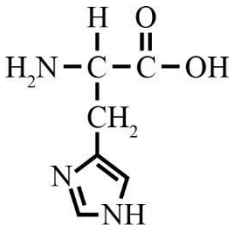
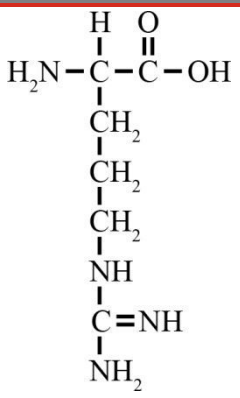
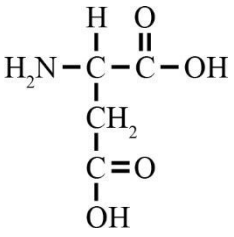
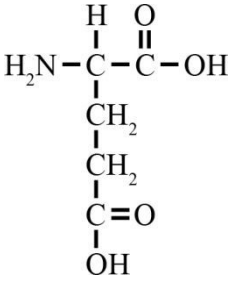
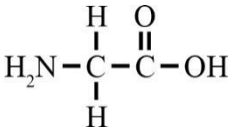
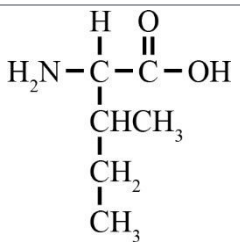



Straight chain D-glucose  *α*-D-glucose

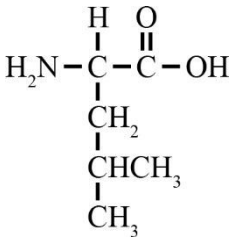
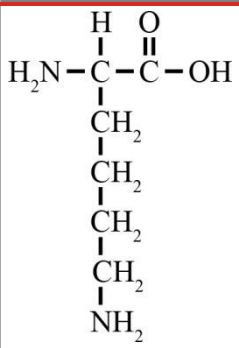
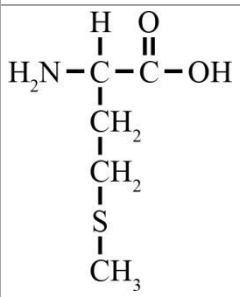
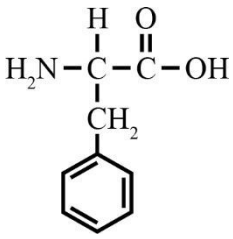
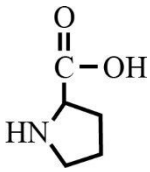
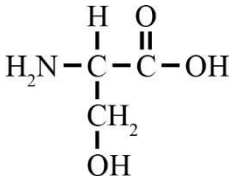
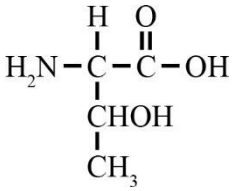
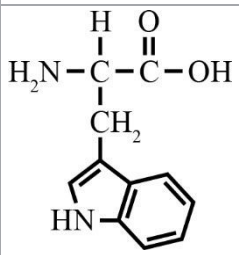
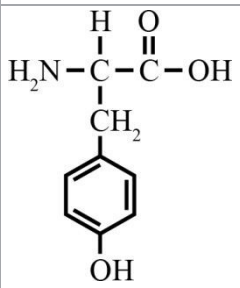
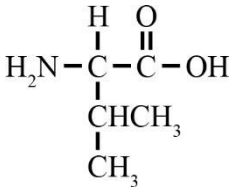



Straight chain D-fructose  *α*-D-fructose

# Common amino acids

| Common name (symbol) | Structural formula | pH of isoelectric point |
|---|---|---|
| Alanine (Ala) |  | 6.1 |
| Asparagine (Asn) |  | 5.4 |
| Cysteine (Cys) |  | 5.1 |
| Glutamine (Gln) |  | 5.7 |
| Histidine (His) |  | 7.6 |
| Arginine (Arg) |  | 10.7 |
| Aspartic acid (Asp) |  | 3.0 |
| Glutamic acid (Glu) |  | 3.2 |
| Glycine (Gly) |  | 6.1 |
| Isoleucine (Ile) |  | 6.0 |

Continued on next page.

| Common name (symbol) | Structural formula | pH of isoelectric point | Common name (symbol) | Structural formula | pH of isoelectric point |
|---|---|---|---|---|---|
| Leucine (Leu) |  | 6.0 | Lysine (Lys) |  | 9.7 |
| Methionine (Met) |  | 5.7 | Phenylalanine (Phe) |  | 5.7 |
| Proline (Pro) |  | 6.3 | Serine (Ser) |  | 5.7 |
| Threonine (Thr) |  | 5.6 | Tryptophan (Trp) |  | 5.9 |
| Tyrosine (Try) |  | 5.7 | Valine (Val) |  | 6.0 |

# Acid-base indicators

| Name | pKa | pH range of colour change | Colour change (acidic to basic) |
|---|---|---|---|
| Methyl orange | 3.7 | 3.1–4.4 | red to yellow |
| Bromophenol blue | 4.2 | 3.0–4.6 | yellow to blue |
| Bromocresol green | 4.7 | 3.8–5.4 | yellow to blue |
| Methyl red | 5.1 | 4.4–6.2 | pink to yellow |
| Bromothymol blue | 7.0 | 6.0–7.6 | yellow to blue |
| Phenol red | 7.9 | 6.8–8.4 | yellow to red |
| Phenolphthalein | 9.6 | 8.3–10.0 | colourless to pink |

# Infrared data

Characteristic range of infrared absorption due to stretching in organic molecules.

| Bond | Organic molecules | Wavelength ($cm^{-1}$) |
|---|---|---|
| C–I | iodoalkanes | 490–620 |
| C–Br | bromoalkanes | 500–600 |
| C–Cl | chloroalkanes | 600–800 |
| C–F | fluoroalkanes | 1000–1400 |
| C–O | alcohol, ester | 1050–1410 |
| C=C | alkenes | 1620–1680 |
| C=O | aldehydes, carboxylic acid, ester, ketones | 1700–1750 |
| C≡C | alkynes | 2100–2260 |
| O–H | carboxylic acids (hydrogen-bonded) | 2500–3000 |
| C–H | alkanes, alkenes, alkynes, aldehydes, amides | 2720–3100 |
| O–H | alcohol (hydrogen-bonded) | 3200–3600 |
| N–H | amines | 3300–3500 |

# Formulas and charges for common polyatomic ions

| Anions | |
|---|---|
| acetate (ethanoate) | $CH_3COO^-$ or $C_2H_3O_2^-$ |
| carbonate | $CO_3^{2-}$ |
| chlorate | $ClO_3^-$ |
| chlorite | $ClO_2^-$ |
| chromate | $CrO_4^{2-}$ |
| citrate | $C_6H_5O_7^{3-}$ |
| cyanide | $CN^-$ |
| dichromate | $Cr_2O_7^{2-}$ |
| dihydrogen phosphate | $H_2PO_4^-$ |
| hypochlorite | $ClO^-$ |
| hydrogen carbonate | $HCO_3^-$ |
| hydrogen sulfate | $HSO_4^-$ |
| hydrogen phosphate | $HPO_4^{2-}$ |
| hydroxide | $OH^-$ |
| nitrate | $NO_3^-$ |
| nitrite | $NO_2^-$ |
| perchlorate | $ClO_4^-$ |
| permanganate | $MnO_4^-$ |
| peroxide | $O_2^{2-}$ |
| phosphate | $PO_4^{3-}$ |
| sulfate | $SO_4^{2-}$ |
| sulfite | $SO_3^{2-}$ |
| thiosulfate | $S_2O_3^{2-}$ |

| Cations | |
|---|---|
| ammonium | $NH_4^+$ |
| hydronium | $H_3O^+$ |