

Chemistry

2026 Data Book

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1. Names of selected elements

Element	Symbol	Atomic number	Relative atomic mass/amu
aluminium	Al	13	27.0
argon	Ar	18	40.0
arsenic	As	33	74.9
barium	Ba	56	137.3
beryllium	Be	4	9.0
boron	B	5	10.8
bromine	Br	35	79.9
cadmium	Cd	48	112.4
caesium	Cs	55	132.9
calcium	Ca	20	40.1
carbon	C	6	12.0
chlorine	Cl	17	35.5
chromium	Cr	24	52.0
cobalt	Co	27	58.9
copper	Cu	29	63.5
fluorine	F	9	19.0
gallium	Ga	31	69.7
germanium	Ge	32	72.6
gold	Au	79	197.0
helium	He	2	4.0
hydrogen	H	1	1.0
iodine	I	53	126.9
iron	Fe	26	55.8
krypton	Kr	36	83.8
lead	Pb	82	207.2
lithium	Li	3	6.9

Element	Symbol	Atomic number	Relative atomic mass/amu
magnesium	Mg	12	24.3
manganese	Mn	25	54.9
mercury	Hg	80	200.6
neon	Ne	10	20.2
nickel	Ni	28	58.7
nitrogen	N	7	14.0
oxygen	O	8	16.0
phosphorus	P	15	31.0
platinum	Pt	78	195.1
potassium	K	19	39.1
rubidium	Rb	37	85.5
scandium	Sc	21	45.0
selenium	Se	34	79.0
silicon	Si	14	28.1
silver	Ag	47	107.9
sodium	Na	11	23.0
strontium	Sr	38	87.6
sulfur	S	16	32.1
tin	Sn	50	118.7
titanium	Ti	22	47.9
tungsten	W	74	183.8
vanadium	V	23	50.9
xenon	Xe	54	131.3
yttrium	Y	39	88.9
zinc	Zn	30	65.4
zirconium	Zr	40	91.2

2. Electrochemical series

Standard reduction potentials, $E^\ominus$, are listed at SLIC (25 °C and 100 kPa). The activity of all soluble species is assumed to be 1.00 M.

Reaction	$E^\ominus(\text{V})$
$\text{F}_2(\text{g}) + 2\text{e}^- \rightleftharpoons 2\text{F}^-(\text{aq})$	+2.89
$\text{H}_2\text{O}_2(\text{aq}) + 2\text{H}^+(\text{aq}) + 2\text{e}^- \rightleftharpoons 2\text{H}_2\text{O}(\text{l})$	+1.76
$\text{MnO}_4^-(\text{aq}) + 8\text{H}^+(\text{aq}) + 5\text{e}^- \rightleftharpoons \text{Mn}^{2+}(\text{aq}) + 4\text{H}_2\text{O}(\text{l})$	+1.51
$\text{PbO}_2(\text{s}) + 4\text{H}^+(\text{aq}) + 2\text{e}^- \rightleftharpoons \text{Pb}^{2+}(\text{aq}) + 2\text{H}_2\text{O}(\text{l})$	+1.46
$\text{Cr}_2\text{O}_7^{2-}(\text{aq}) + 14\text{H}^+(\text{aq}) + 6\text{e}^- \rightleftharpoons 2\text{Cr}^{3+}(\text{aq}) + 7\text{H}_2\text{O}(\text{l})$	+1.36
$\text{Cl}_2(\text{g}) + 2\text{e}^- \rightleftharpoons 2\text{Cl}^-(\text{aq})$	+1.36
$\text{O}_2(\text{g}) + 4\text{H}^+(\text{aq}) + 4\text{e}^- \rightleftharpoons 2\text{H}_2\text{O}(\text{l})$	+1.23
$\text{Br}_2(\text{l}) + 2\text{e}^- \rightleftharpoons 2\text{Br}^-(\text{aq})$	+1.08
$\text{Ag}^+(\text{aq}) + \text{e}^- \rightleftharpoons \text{Ag}(\text{s})$	+0.80
$\text{Fe}^{3+}(\text{aq}) + \text{e}^- \rightleftharpoons \text{Fe}^{2+}(\text{aq})$	+0.77
$\text{O}_2(\text{g}) + 2\text{H}^+(\text{aq}) + 2\text{e}^- \rightleftharpoons \text{H}_2\text{O}_2(\text{aq})$	+0.70
$\text{I}_2(\text{s}) + 2\text{e}^- \rightleftharpoons 2\text{I}^-(\text{aq})$	+0.54
$\text{O}_2(\text{g}) + 2\text{H}_2\text{O}(\text{l}) + 4\text{e}^- \rightleftharpoons 4\text{OH}^-(\text{aq})$	+0.40
$\text{Cu}^{2+}(\text{aq}) + 2\text{e}^- \rightleftharpoons \text{Cu}(\text{s})$	+0.34
$\text{Sn}^{4+}(\text{aq}) + 2\text{e}^- \rightleftharpoons \text{Sn}^{2+}(\text{aq})$	+0.15
$2\text{H}^+(\text{aq}) + 2\text{e}^- \rightleftharpoons \text{H}_2(\text{g})$	0.00
$\text{Pb}^{2+}(\text{aq}) + 2\text{e}^- \rightleftharpoons \text{Pb}(\text{s})$	-0.13
$\text{Sn}^{2+}(\text{aq}) + 2\text{e}^- \rightleftharpoons \text{Sn}(\text{s})$	-0.14
$\text{Ni}^{2+}(\text{aq}) + 2\text{e}^- \rightleftharpoons \text{Ni}(\text{s})$	-0.24
$\text{Co}^{2+}(\text{aq}) + 2\text{e}^- \rightleftharpoons \text{Co}(\text{s})$	-0.28
$\text{Fe}^{2+}(\text{aq}) + 2\text{e}^- \rightleftharpoons \text{Fe}(\text{s})$	-0.44
$\text{Zn}^{2+}(\text{aq}) + 2\text{e}^- \rightleftharpoons \text{Zn}(\text{s})$	-0.76
$2\text{H}_2\text{O}(\text{l}) + 2\text{e}^- \rightleftharpoons \text{H}_2(\text{g}) + 2\text{OH}^-(\text{aq})$	-0.83
$\text{Mn}^{2+}(\text{aq}) + 2\text{e}^- \rightleftharpoons \text{Mn}(\text{s})$	-1.18
$\text{Al}^{3+}(\text{aq}) + 3\text{e}^- \rightleftharpoons \text{Al}(\text{s})$	-1.68
$\text{Mg}^{2+}(\text{aq}) + 2\text{e}^- \rightleftharpoons \text{Mg}(\text{s})$	-2.36
$\text{Na}^+(\text{aq}) + \text{e}^- \rightleftharpoons \text{Na}(\text{s})$	-2.71
$\text{Ca}^{2+}(\text{aq}) + 2\text{e}^- \rightleftharpoons \text{Ca}(\text{s})$	-2.87
$\text{K}^+(\text{aq}) + \text{e}^- \rightleftharpoons \text{K}(\text{s})$	-2.94
$\text{Li}^+(\text{aq}) + \text{e}^- \rightleftharpoons \text{Li}(\text{s})$	-3.04

3. Chemical relationships

Name	Formula
amount of substance (number of moles)	$n = \frac{m}{M}; \quad n = cV; \quad n = \frac{N}{N_A}$
concentration (parts per million)	$C_{\text{ppm}} = \frac{\text{mass of solute (in mg)}}{\text{mass of solution (in kg)}}$
density	$\rho = \frac{m}{V}$
ideal gas equation	$pV = nRT$
enthalpy change of a reaction	$\Delta H = H_{\text{products}} - H_{\text{reactants}}$
heat gained or lost	$q = mc\Delta T$
molar enthalpy change	$\Delta H = \frac{q}{n}$
electric charge	$Q = It$
amount of electrons (number of moles)	$n(e^-) = \frac{Q}{F}$
electrical energy	$E = VIt$
calibration factor (CF) for general calorimetry	$CF = \frac{E}{\Delta T}$
calibration factor (CF) for reaction calorimetry	$CF = \frac{n\Delta H}{\Delta T}$
standard cell potential	$E^{\ominus}_{\text{cell}} = E^{\ominus}_{\text{(reduction half-cell)}} - E^{\ominus}_{\text{(oxidation half-cell)}}$
percentage atom economy	$\% \text{ atom economy} = \frac{\text{molar mass of desired product}}{\text{molar mass of all atoms in reactants}} \times \frac{100}{1}$
percentage yield	$\% \text{ yield} = \frac{\text{actual yield}}{\text{theoretical yield}} \times \frac{100}{1}$
equilibrium constant	$K_c = \frac{[C]^y \times [D]^z \times \dots}{[A]^w \times [B]^x \times \dots}$ for the equation $wA + xB + \dots \rightleftharpoons yC + zD + \dots$

4. Physical constants and standard values

Name	Symbol	Value
Avogadro constant	N_A or L	$6.02 \times 10^{23} \text{ mol}^{-1}$
Faraday constant	F	$96\,500 \text{ C mol}^{-1}$
molar gas constant	R	$8.31 \text{ J mol}^{-1} \text{ K}^{-1}$
molar volume of an ideal gas at SLC (25 °C and 100 kPa)	V_m	24.8 L mol^{-1}
specific heat capacity of water	c_w	$4.18 \text{ kJ kg}^{-1} \text{ K}^{-1}$ or $4.18 \text{ J g}^{-1} \text{ K}^{-1}$
density of water at 25 °C	ρ	1.0 g mL^{-1}
molar latent heat of vaporisation of water at 25 °C	$\Delta H_{\text{vap}}(\text{H}_2\text{O})$	$+44.0 \text{ kJ mol}^{-1}$
molar latent heat of vaporisation of water at 100 °C	$\Delta H_{\text{vap}}(\text{H}_2\text{O})$	$+40.7 \text{ kJ mol}^{-1}$

5. Unit conversions

Measured value	Conversion
0 °C	273 K
100 kPa	0.987 atm
1 litre (L)	1 dm^3 or $1 \times 10^{-3} \text{ m}^3$ or $1 \times 10^3 \text{ cm}^3$ or $1 \times 10^3 \text{ mL}$
1 tonne (t)	$1 \times 10^3 \text{ kg}$ or $1 \times 10^6 \text{ g}$

6. Metric prefixes

The following prefixes are commonly used within the International System of Units (SI) to modify the base units and express quantities in multiples or fractions of those units.

Prefixes	Scientific notation	Multiplying factor
giga (G)	10^9	1 000 000 000
mega (M)	10^6	1 000 000
kilo (k)	10^3	1000
deci (d)	10^{-1}	0.1
centi (c)	10^{-2}	0.01
milli (m)	10^{-3}	0.001
micro (μ)	10^{-6}	0.000 001
nano (n)	10^{-9}	0.000 000 001
pico (p)	10^{-12}	0.000 000 000 001

7. Acid-base indicators

Name	pH range	Colour change from lower pH to higher pH in range
thymol blue (1st change)	1.2–2.8	red → yellow
methyl orange	3.1–4.4	red → orange
bromophenol blue	3.0–4.6	yellow → blue-violet
bromocresol green	4.0–5.6	yellow → blue
methyl red	4.4–6.2	red → yellow
bromothymol blue	6.0–7.6	yellow → blue
phenol red	6.4–8.0	yellow → red
thymol blue (2nd change)	8.0–9.6	yellow → blue
phenolphthalein	8.0–10.0	colourless → pink (dilute) colourless → red (concentrated)

8. Colours of selected oxidising agents and their conjugate reducing agents

The listed conjugate reducing agents are formed only under appropriate reaction conditions, particularly with respect to solution acidity. Under different conditions, alternative products may be formed. Solution concentrations may also influence observed colours.

Oxidising agent			Conjugate reducing agent		
Name	Formula	Colour of aqueous solution	Name	Formula	Colour of solid or aqueous solution
bromine	Br_2	reddish-brown	bromide ion	Br^-	colourless solution
chlorine	Cl_2	pale yellow-green	chloride ion	Cl^-	colourless solution
cobalt ion	Co^{2+}	pink	cobalt metal	Co	silver solid
copper(II) ion	Cu^{2+}	blue	copper metal	Cu	red-brown solid
dichromate ion	$\text{Cr}_2\text{O}_7^{2-}$	orange	chromium(III) ion	Cr^{3+}	green solution
iodine	I_2	brown in aqueous solutions	iodide ion	I^-	colourless solution
iron(III) ion	Fe^{3+}	yellow/brown	iron(II) ion	Fe^{2+}	pale green solution
iron(II) ion ²	Fe^{2+}	pale green	iron metal	Fe	silver solid
manganese(IV) dioxide	MnO_2	black/brown	manganese(II) ion	Mn^{2+}	colourless solution (dilute) very pale pink solution (concentrated)
nickel ion	Ni^{2+}	green	nickel metal	Ni	silver solid
permanganate ion	MnO_4^-	intense purple	manganese(II) ion	Mn^{2+}	colourless solution (dilute) very pale pink solution (concentrated)

Note: Starch solution can be added to a reaction mixture to detect the presence of iodine at low concentrations. This forms a blue-black starch-iodine complex, which is easier to see than the very pale brown colour of a dilute iodine solution.

9. Formulas and charges for selected ions

Cations

1+		2+		3+	
Name	Formula	Name	Formula	Name	Formula
ammonium	NH ₄ ⁺	barium	Ba ²⁺	aluminium	Al ³⁺
copper(I)	Cu ⁺	calcium	Ca ²⁺	chromium(III)	Cr ³⁺
hydronium	H ₃ O ⁺	copper(II)	Cu ²⁺	iron(III)	Fe ³⁺
lithium	Li ⁺	iron(II)	Fe ²⁺	4+	
potassium	K ⁺	lead(II)	Pb ²⁺	titanium(IV)	Ti ⁴⁺
silver	Ag ⁺	magnesium	Mg ²⁺		
sodium	Na ⁺	mercury(II)	Hg ²⁺		
		nickel(II)	Ni ²⁺		
		tin(II)	Sn ²⁺		
		zinc	Zn ²⁺		

Anions

1-			
Name	Formula	Name	Formula
bromide	Br^-	hydrosulfide	HS^-
chlorate	ClO_3^-	hydrosulfite	HSO_3^-
chloride	Cl^-	hydroxide	OH^-
chlorite	ClO_2^-	hypochlorite	ClO^-
cyanide	CN^-	iodide	I^-
dihydrogenphosphate	H_2PO_4^-	nitrate	NO_3^-
ethanoate	CH_3COO^-	nitrite	NO_2^-
fluoride	F^-	perchlorate	ClO_4^-
hydrogencarbonate	HCO_3^-	permanganate	MnO_4^-
hydrosulfate	HSO_4^-		

2-			
Name	Formula	Name	Formula
carbonate	CO_3^{2-}	peroxide	O_2^{2-}
chromate	CrO_4^{2-}	sulfate	SO_4^{2-}
dichromate	$\text{Cr}_2\text{O}_7^{2-}$	sulfide	S^{2-}
monohydrogenphosphate	HPO_4^{2-}	sulfite	SO_3^{2-}
oxide	O^{2-}	thiosulfate	$\text{S}_2\text{O}_3^{2-}$

3-		
Name	Formula	
citrate	$\text{C}_6\text{H}_5\text{O}_7^{3-}$	
nitride	N^{3-}	
phosphate	PO_4^{3-}	

10. Qualitative solubilities of selected ionic salts in water

Solubility data in the table below is based on mass, in grams, of anhydrous substance per 100 g water required to prepare a saturated solution at 298 K.

Anion Cation	bromide Br^-	carbonate CO_3^{2-}	chloride Cl^-	hydroxide OH^-	iodide I^-	nitrate NO_3^-	oxide O_2^-	phosphate PO_4^{3-}	sulfate SO_4^{2-}
aluminium Al^{3+}	s		s	i	s	s	i	i	s
ammonium NH_4^+	s	s	s		s	s		s	s
barium Ba^{2+}	s	i	s	s	s	s	s	i	i
calcium Ca^{2+}	s	i	s	ss	s	s	s	i	ss
cobalt(II) Co^{2+}	s	i	s	i	s	s	i	i	s
copper(II) Cu^{2+}	s	i	s	i		s	i	i	s
iron(II) Fe^{2+}	s	ss	s	i	s	s	i	i	s
iron(III) Fe^{3+}	s		s	i		s	i	i	s
lead(II) Pb^{2+}	ss	i	ss	ss	ss	s	i	i	i
magnesium Mg^{2+}	s	ss	s	i	s	s	i	i	s
manganese(II) Mn^{2+}	s	i	s	i	s	s	i	i	s
nickel(II) Ni^{2+}	s	i	s	i	s	s	i	i	s
potassium K^+	s	s	s	s	s	s	s	s	s
silver Ag^+	i	i	i		i	s	i	i	ss
sodium Na^+	s	s	s	s	s	s		s	s
strontium Sr^{2+}	s	i	s	ss	s	s	ss	ss	ss
zinc Zn^{2+}	s	ss	s	i	s	s	i	i	s

Key

Abbreviation	Description
s	soluble in water (more than 3 g of solute will dissolve in 100 mL of water)
ss	sparingly soluble in water (between 0.01 g and 3 g of solute will dissolve in 100 mL of water)
i	insoluble in water (less than 0.01 g of solute will dissolve in 100 mL of water)
(blank)	no reliable data (salt decomposes or reacts in water before dissolving)

11. Energy content of biomolecules in food

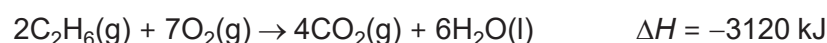
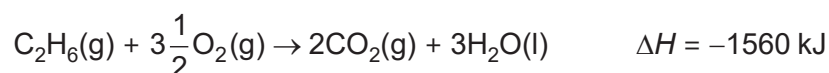
The energy that is typically available for the body to use as a result of the digestion and absorption of fats and oils, proteins and carbohydrates is shown in the table below. These values may vary based on the specific composition of foods and individual metabolic factors.

Biomolecules	Energy content (kJ g ⁻¹)
fats and oils	37
proteins	17
carbohydrates	16

12. Molar enthalpies of combustion

The molar enthalpies of combustion in the following table are calculated at SLC (25 °C and 100 kPa) with combustion products being CO₂(g) and H₂O(l). Enthalpies of combustion, ΔH , for the substances in this table are reported for one mole of fuel and are shown as negative values, indicating the exothermic nature of the combustion reaction.

ΔH values are equation-dependent.



Fuel	Formula	Molar enthalpy of combustion (kJ mol ⁻¹)
hydrogen	H ₂ (g)	-286
methane	CH ₄ (g)	-890
ethane	C ₂ H ₆ (g)	-1560
propane	C ₃ H ₈ (g)	-2220
butane	C ₄ H ₁₀ (g)	-2877
octane	C ₈ H ₁₈ (l)	-5470
methanol	CH ₃ OH(l)	-726
ethanol	C ₂ H ₅ OH(l)	-1367
carbon (graphite)	C(s)	-394
glucose	C ₆ H ₁₂ O ₆ (s)	-2803

13. Heats of combustion of selected fossil fuels

The following table provides typical values for the heats of combustion of selected fossil fuels at SLC (25 °C and 100 kPa), with the combustion products being $\text{CO}_2(\text{g})$ and $\text{H}_2\text{O}(\text{l})$. The values for the heats of combustion will vary due to the composition of the different fuels. The listed fossil fuels are mixtures of compounds, so the molar composition is variable. Additionally, for natural gas, the values may vary based on the source and processing.

Fuel	State	Heat of combustion (kJ g^{-1})	Heat of combustion (kJ mL^{-1})
diesel	liquid	45	37
kerosene	liquid	46	37
natural gas	gas	54	0.035
petrol	liquid	45	34

14. Heats of combustion of selected biofuels

The following table provides typical values for the heats of combustion of selected biofuels. The values for the heats of combustion may vary significantly, particularly for biogas, depending on the source of the biofuel and, hence, its composition. The amount of energy consumed during any purification process must also be considered when determining the net energy obtained from a biofuel.

Fuel	State	Heat of combustion (kJ g^{-1})
biodiesel	liquid	approximately 37 This varies slightly depending on the feedstock used to produce it.
bioethanol	liquid	29.7
biogas	gas	14–24 This depends on its methane content, which can vary from 45% to 75% methane by volume, depending on its source. The other main constituent is CO_2 , which does not burn. Some samples may also contain a small amount of gases, such as H_2S and water vapour.

1		2		3		4		5		6		7		8		9	
1	2.2	3	1.0	4	1.6	5	1.0	6	1.5	7	1.7	8	1.6	9	1.8	10	1.9
H 1.0 hydrogen		Li 6.9 lithium		Be 9.0 beryllium		B 10.8 boron		C 12.0 carbon		N 14.0 nitrogen		O 16.0 oxygen		F 19.0 fluorine		Ne 20.2 neon	
11	0.9	12	1.3	13	1.0	14	1.5	15	1.7	16	1.6	17	1.8	18	1.7	19	1.9
Na 23.0 sodium		Mg 24.3 magnesium		Al 27.0 aluminum		Si 28.1 silicon		P 31.0 phosphorus		S 32.1 sulfur		Cl 35.5 chlorine		Ar 39.9 argon		K 39.1 potassium	
37	0.8	38	1.0	39	1.2	40	1.3	41	1.6	42	2.2	43	1.9	44	2.2	45	2.3
Rb 85.5 rubidium		Sr 87.6 strontium		Y 88.9 yttrium		Zr 91.2 zirconium		Nb 92.9 niobium		Mo 96.0 molybdenum		Tc (97) technetium		Ru 101.1 ruthenium		Rh 102.9 rhodium	
55	0.8	56	0.9	57–71 lanthanoids		72	1.3	73	1.5	74	2.4	75	1.9	76	2.2	77	2.2
Cs 132.9 caesium		Ba 137.3 barium				Hf 178.5 hafnium		Ta 181.0 tantalum		W 183.8 tungsten		Re 186.2 rhenium		Os 190.2 osmium		Ir 192.2 iridium	
87	0.7	88	0.9	89–103 actinoids		104		105		106		107		108		109	
Fr (223) francium		Ra (226) radium				Rf (267) rutherfordium		Db (268) dubnium		Sg (269) seaborgium		Bh (270) bohrium		Hs (269) hassium		Mt (277) meitnerium	
						57	1.1	58	1.1	59	1.1	60	1.1	61		62	1.2
						La 138.9 lanthanum		Ce 140.1 cerium		Pr 140.9 praseodymium		Nd 144.2 neodymium		Pm (145) promethium		Sm 150.4 samarium	
						89	1.1	90	1.3	91	1.5	92	1.4	93	1.4	94	1.3
						Ac (227) actinium		Th 232.0 thorium		Pa 231.0 protactinium		U 238.0 uranium		Np (237) neptunium		Pu (244) plutonium	

									18
									2
									He 4.0 helium
			13	14	15	16	17		
			5 2.0 B 10.8 boron	6 2.6 C 12.0 carbon	7 3.0 N 14.0 nitrogen	8 3.4 O 16.0 oxygen	9 4.0 F 19.0 fluorine	10 Ne 20.2 neon	
			13 1.6 Al 27.0 aluminium	14 1.9 Si 28.1 silicon	15 2.2 P 31.0 phosphorus	16 2.6 S 32.1 sulfur	17 3.2 Cl 35.5 chlorine	18 Ar 40.0 argon	
10	11	12							
28 1.9 Ni 58.7 nickel	29 1.9 Cu 63.5 copper	30 1.7 Zn 65.4 zinc	31 1.8 Ga 69.7 gallium	32 2.0 Ge 72.6 germanium	33 2.2 As 74.9 arsenic	34 2.6 Se 79.0 selenium	35 3.0 Br 79.9 bromine	36 3.0 Kr 83.8 krypton	
46 2.2 Pd 106.4 palladium	47 1.9 Ag 107.9 silver	48 1.7 Cd 112.4 cadmium	49 1.8 In 114.8 indium	50 2.0 Sn 118.7 tin	51 2.1 Sb 121.8 antimony	52 2.1 Te 127.6 tellurium	53 2.7 I 126.9 iodine	54 2.6 Xe 131.3 xenon	
78 2.3 Pt 195.1 platinum	79 2.5 Au 197.0 gold	80 2.0 Hg 200.6 mercury	81 1.6 Tl 204.4 thallium	82 2.3 Pb 207.2 lead	83 2.0 Bi 209.0 bismuth	84 2.0 Po (209) polonium	85 2.2 At (210) astatine	86 Rn (222) radon	
110 Ds (281) darmstadtium	111 Rg (282) roentgenium	112 Cn (285) copernicium	113 Nh (286) nihonium	114 Fl (290) flerovium	115 Mc (290) moscovium	116 Lv (293) livermorium	117 Ts (294) tennessine	118 Og (294) oganesson	

63 Eu 152.0 europium	64 1.2 Gd 157.3 gadolinium	65 Tb 158.9 terbium	66 1.2 Dy 162.5 dysprosium	67 1.2 Ho 164.9 holmium	68 1.2 Er 167.3 erbium	69 1.3 Tm 168.9 thulium	70 Yb 173.1 ytterbium	71 1.3 Lu 175.0 lutetium
---	--	--	--	---	--	---	--	--

95 1.3 Am (243) americium	96 1.3 Cm (247) curium	97 1.3 Bk (247) berkelium	98 1.3 Cf (251) californium	99 1.3 Es (252) einsteinium	100 1.3 Fm (257) fermium	101 1.3 Md (258) mendelevium	102 1.3 No (259) nobelium	103 1.3 Lr (262) lawrencium
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Notes

- Groups are numbered according to IUPAC convention.
- Values in brackets indicate the mass number of the longest-lived isotope of that element.

16. Formats for representing organic molecules

The following table shows different representations of organic molecules, using butanoic acid as an example.

Formula	Representation
molecular formula	$C_4H_8O_2$
structural formula	
semi-structural (condensed) formula	$CH_3CH_2CH_2COOH$ or $CH_3(CH_2)_2COOH$
skeletal structure	

17. Functional group and substituent nomenclature in organic chemistry

The following table shows the most common functional groups and substituents, categorised by their priority according to IUPAC rules for naming organic compounds with multiple functional groups.

The table also shows their suffixes and prefixes, where relevant for VCE Chemistry. The functional group with the highest priority determines the compound's suffix. Lower-priority functional groups and substituents may be indicated as prefixes.

IUPAC class	IUPAC functional group structure	Prefix	Suffix
carboxylic acid	$-COOH$	*	-oic acid
ester	$-COOR$ (where R is an alkyl group)–	*	-oate
aldehyde	$-CHO$	*	-al
ketone	$-CO-$	*	-one
alcohol	$-OH$	hydroxy-	-ol
amine	$-NH_2$	amino-	-amine
alkene	$>C=C<$	*	-ene
halogen and alkyl substituents	$-X$ (where X = F, Cl, Br or I) $-R$ (where R is an alkyl group)	fluoro-, chloro-, bromo-, iodo- methyl-, ethyl-, propyl-, butyl-, pentyl-, hexyl-, heptyl-, octyl-	–

Note: The * indicates that use of this prefix is beyond the scope of VCE Chemistry.

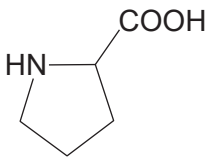
18. Formulas of selected fatty acids

Name	Molecular formula	State at SLC	Representation
caproic	$C_6H_{12}O_2$	liquid	$CH_3(CH_2)_4COOH$
capric	$C_{10}H_{20}O_2$	solid	$CH_3(CH_2)_8COOH$
lauric	$C_{12}H_{24}O_2$	solid	$CH_3(CH_2)_{10}COOH$
myristic	$C_{14}H_{28}O_2$	solid	$CH_3(CH_2)_{12}COOH$
palmitic	$C_{16}H_{32}O_2$	solid	$CH_3(CH_2)_{14}COOH$
palmitoleic	$C_{16}H_{30}O_2$	liquid	$CH_3(CH_2)_5CH=CH(CH_2)_7COOH$
stearic	$C_{18}H_{36}O_2$	solid	$CH_3(CH_2)_{16}COOH$
oleic	$C_{18}H_{34}O_2$	liquid	$CH_3(CH_2)_7CH=CH(CH_2)_7COOH$
linoleic	$C_{18}H_{32}O_2$	liquid	$CH_3(CH_2)_4CH=CHCH_2CH=CH(CH_2)_7COOH$
linolenic	$C_{18}H_{30}O_2$	liquid	$CH_3(CH_2CH=CH)_3(CH_2)_7COOH$
arachidic	$C_{20}H_{40}O_2$	solid	$CH_3(CH_2)_{18}COOH$
arachidonic	$C_{20}H_{32}O_2$	liquid	$CH_3(CH_2)_4(CH=CHCH_2)_3CH=CH(CH_2)_3COOH$

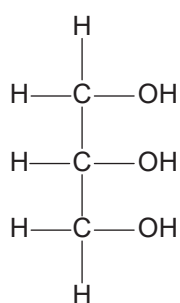
19. 2-amino acids

The following table provides simplified structures for amino acids. These amino acids may all be classified as 2-amino acids since the amino group ($-\text{NH}_2$) is attached to the second carbon atom in the carbon chain, numbered from the carboxyl ($-\text{COOH}$) end. These structures may be used as the basis for drawing zwitterions, identifying the products of protein hydrolysis and drawing the structures formed in the condensation polymerisation of amino acid monomers.

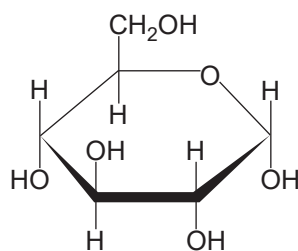
Name	Symbol	Structure
alanine	Ala	$\begin{array}{c} \text{CH}_3 \\ \\ \text{H}_2\text{N}-\text{CH}-\text{COOH} \end{array}$
arginine	Arg	$\begin{array}{c} \text{CH}_2-\text{CH}_2-\text{CH}_2-\text{NH}-\text{C}(=\text{NH})-\text{NH}_2 \\ \\ \text{H}_2\text{N}-\text{CH}-\text{COOH} \end{array}$
asparagine	Asn	$\begin{array}{c} \text{O} \\ \\ \text{CH}_2-\text{C}-\text{NH}_2 \\ \\ \text{H}_2\text{N}-\text{CH}-\text{COOH} \end{array}$
aspartic acid	Asp	$\begin{array}{c} \text{CH}_2-\text{COOH} \\ \\ \text{H}_2\text{N}-\text{CH}-\text{COOH} \end{array}$
cysteine	Cys	$\begin{array}{c} \text{CH}_2-\text{SH} \\ \\ \text{H}_2\text{N}-\text{CH}-\text{COOH} \end{array}$
glutamic acid	Glu	$\begin{array}{c} \text{CH}_2-\text{CH}_2-\text{COOH} \\ \\ \text{H}_2\text{N}-\text{CH}-\text{COOH} \end{array}$
glutamine	Gln	$\begin{array}{c} \text{O} \\ \\ \text{CH}_2-\text{CH}_2-\text{C}-\text{NH}_2 \\ \\ \text{H}_2\text{N}-\text{CH}-\text{COOH} \end{array}$
glycine	Gly	$\text{H}_2\text{N}-\text{CH}_2-\text{COOH}$
histidine	His	$\begin{array}{c} \text{N} \\ // \quad \backslash \\ \text{CH}_2-\text{C} \quad \text{N}-\text{H} \\ \\ \text{H}_2\text{N}-\text{CH}-\text{COOH} \end{array}$

Name	Symbol	Structure
isoleucine	Ile	$\begin{array}{c} \text{CH}_3\text{---CH---CH}_2\text{---CH}_3 \\ \\ \text{H}_2\text{N---CH---COOH} \end{array}$
leucine	Leu	$\begin{array}{c} \text{CH}_3\text{---CH---CH}_3 \\ \\ \text{CH}_2 \\ \\ \text{H}_2\text{N---CH---COOH} \end{array}$
lysine	Lys	$\begin{array}{c} \text{CH}_2\text{---CH}_2\text{---CH}_2\text{---CH}_2\text{---NH}_2 \\ \\ \text{H}_2\text{N---CH---COOH} \end{array}$
methionine	Met	$\begin{array}{c} \text{CH}_2\text{---CH}_2\text{---S---CH}_3 \\ \\ \text{H}_2\text{N---CH---COOH} \end{array}$
phenylalanine	Phe	$\begin{array}{c} \text{CH}_2\text{---} \text{C}_6\text{H}_5 \\ \\ \text{H}_2\text{N---CH---COOH} \end{array}$
proline	Pro	
serine	Ser	$\begin{array}{c} \text{CH}_2\text{---OH} \\ \\ \text{H}_2\text{N---CH---COOH} \end{array}$
threonine	Thr	$\begin{array}{c} \text{CH}_3\text{---CH---OH} \\ \\ \text{H}_2\text{N---CH---COOH} \end{array}$
tryptophan	Trp	$\begin{array}{c} \text{HN} \\ \diagup \quad \diagdown \\ \text{CH}_2\text{---} \text{C}_8\text{H}_6\text{N} \\ \\ \text{H}_2\text{N---CH---COOH} \end{array}$
tyrosine	Tyr	$\begin{array}{c} \text{CH}_2\text{---} \text{C}_6\text{H}_4\text{---OH} \\ \\ \text{H}_2\text{N---CH---COOH} \end{array}$
valine	Val	$\begin{array}{c} \text{CH}_3\text{---CH---CH}_3 \\ \\ \text{H}_2\text{N---CH---COOH} \end{array}$

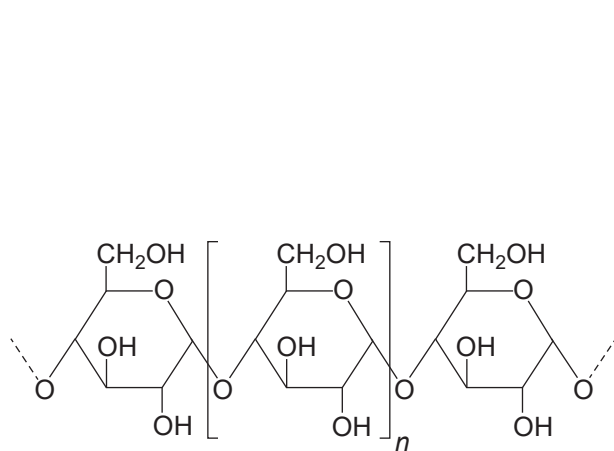
20. Representation of selected biomolecules



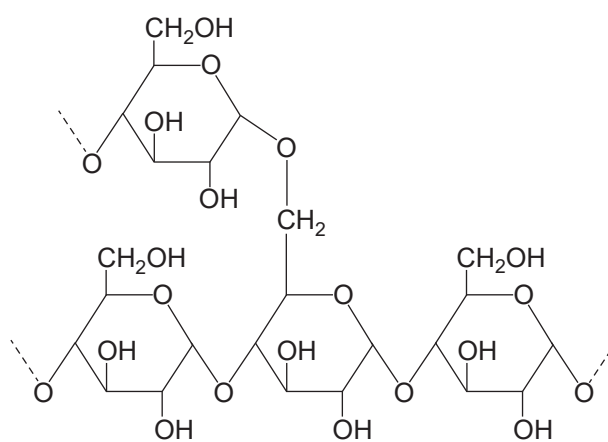
Glycerol



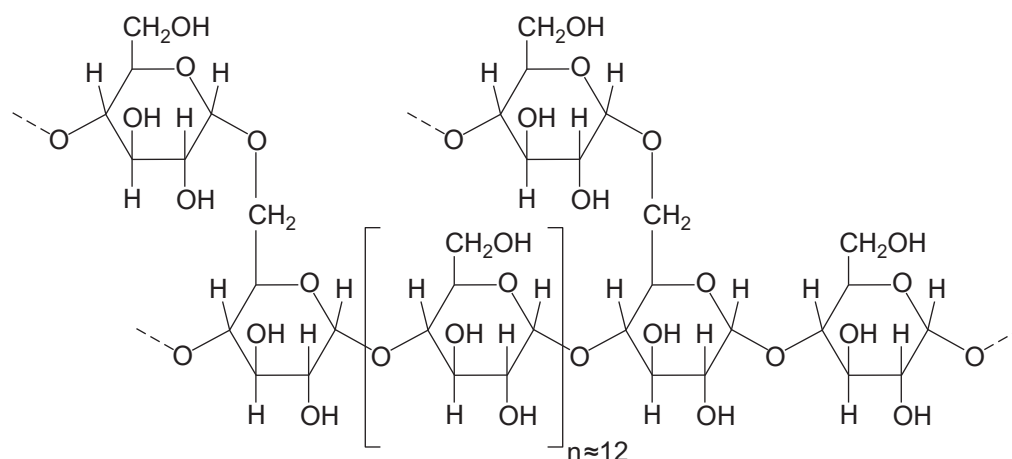
α -D-glucose



Amylose (starch)



Amylopectin (starch)



Glycogen

21. Characteristic ranges for infrared absorption

Bond	Wavenumber (cm ⁻¹)	Bond	Wavenumber (cm ⁻¹)
C=O (amides)	1630–1680	C–H (alkanes, alkenes, arenes)	2850–3090
C=O (aldehydes)	1660–1745	O–H (acids)	2500–3500
C=O (acids)	1680–1740	O–H (alcohols)	3200–3600
C=O (ketones)	1680–1700	N–H (amines and amides)	3300–3500
C=O (esters)	1720–1750		

22. ¹³C-NMR data

Typical ¹³C shift values relative to TMS = 0

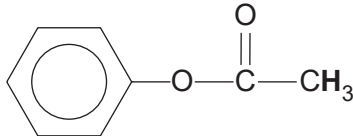
The values depend on the chemical environment and may vary with solvent choice.

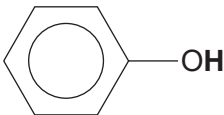
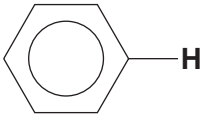
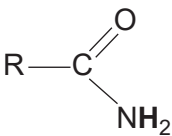
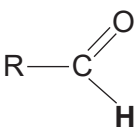
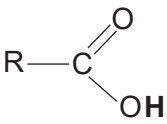
Type of carbon	Chemical shift (ppm)
R–CH ₃	8–25
R–CH ₂ –R	20–45
R ₃ –CH	40–60
R ₄ –C	36–45
R–CH ₂ –X	15–80
R ₃ C–NH ₂ , R ₃ C–NR	35–70
R–CH ₂ –OH	50–90
R ₂ C=CR ₂	110–150
C ₆ H ₅ –R (arenes)	110–150
RCOOH	160–185
$\begin{array}{c} \text{R} \\ \diagdown \\ \text{C}=\text{O} \\ \diagup \\ \text{RO} \end{array}$	165–175
$\begin{array}{c} \text{R} \\ \diagdown \\ \text{C}=\text{O} \\ \diagup \\ \text{H}_2\text{N} \end{array}$	165–185
$\begin{array}{c} \text{R} \\ \diagdown \\ \text{C}=\text{O} \\ \diagup \\ \text{H} \end{array}$	190–200
R ₂ C=O	205–220

23. $^1\text{H-NMR}$ data

Typical proton shift values relative to TMS = 0

The values depend on the chemical environment and may vary with solvent choice. The shift refers to the proton environment that is indicated in bold font in the formula.

Type of proton	Chemical shift (ppm)
R-CH_3	0.9–1.0
$\text{R-CH}_2\text{-R}$	1.3–1.4
RHC=CH-CH_3	1.6–1.9
$\text{R}_3\text{-CH}$	1.5
$\text{CH}_3\text{-}\overset{\text{O}}{\parallel}{\text{C}}\text{-OR}$ or $\text{CH}_3\text{-}\overset{\text{O}}{\parallel}{\text{C}}\text{-NHR}$	2.0
$\text{R-}\overset{\text{CH}_3}{\underset{\text{O}}{\parallel}{\text{C}}}\text{-}$	2.1–2.7
$\text{R-CH}_2\text{-X}$ (X = F, Cl, Br or I)	3.0–4.5
$\text{R-CH}_2\text{-OH}$, $\text{R}_2\text{-CH-OH}$	3.3–4.5
$\text{R-}\overset{\text{O}}{\parallel}{\text{C}}\text{-NHCH}_2\text{R}$	3.2
R-O-CH_3 or $\text{R-O-CH}_2\text{R}$	3.3–3.7
	2.3
$\text{R-}\overset{\text{O}}{\parallel}{\text{C}}\text{-OCH}_2\text{R}$	3.7–4.8
R-OH	1–6 (varies considerably under different conditions)
R-NH_2	1–5
RHC=CHR	4.5–7.0

Type of proton	Chemical shift (ppm)
	4.0–12.0
	6.9–9.0
	6.0–8.0
	9.4–10.0
	9.0–13.0

24. Sustainability

Sustainability is considered in terms of the United Nations Sustainable Development Goals and green chemistry principles, along with linear and circular economies.

i. United Nations Sustainable Development Goals

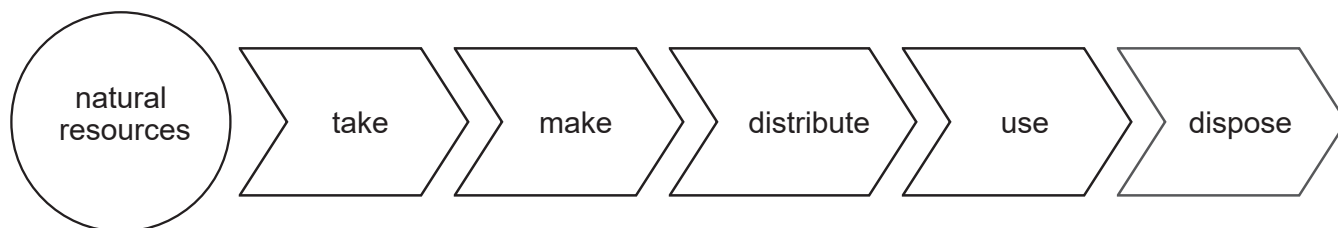
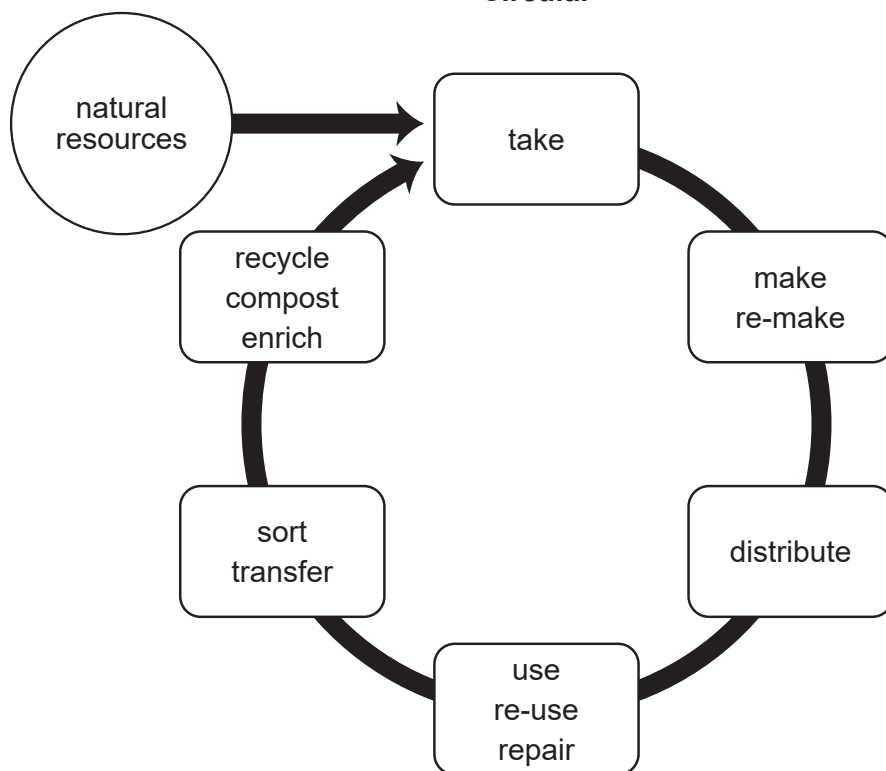
The following nine goals are relevant to VCE Chemistry:

- Goal 2: Zero hunger
- Goal 6: Clean water and sanitation
- Goal 7: Affordable and clean energy
- Goal 9: Industry, innovation and infrastructure
- Goal 11: Sustainable cities and communities
- Goal 12: Responsible consumption and production
- Goal 13: Climate action
- Goal 14: Life below water
- Goal 15: Life on land

ii. Green chemistry principles

The following seven green chemistry principles are relevant to VCE Chemistry:

- Atom economy
Processes/pathways should be designed to maximise incorporation of all reactant materials used in the process into the final product.
- Catalysis
Catalysts should be selected to generate the same desired product(s) with less waste and using less energy and reagents in reaction processes/pathways.
- Design for degradation
Chemical products should be designed so that at the end of their use they break down into harmless degradation products and do not persist in the environment.
- Design for energy efficiency
Processes/pathways should be designed for maximum energy efficiency and with minimal negative environmental and economic impacts.
- Designing safer chemicals
Chemical products should be designed to achieve their intended function while minimising toxicity.
- Prevention of wastes
It is better to prevent waste than to treat or clean up waste after it has been produced.
- Use of renewable feedstocks
Raw materials or feedstocks should be made from renewable (mainly plant-based) materials, rather than from fossil fuels, whenever practicable.

iii. Types of economies**Linear****Circular**

25. References

Data for Items 2, 3, 4, 5, 6, 7, 9, 10, 12, 18, 21, 22 and 23 was taken fully or in part from:

A Blackman and LR Gahan, *Aylward and Findlay's SI Chemical Data*, 7th edition, John Wiley and Sons, Milton, 2013

NG Connelly, et al. (eds), *Nomenclature of Inorganic Chemistry: IUPAC Recommendations 2005*, RSC Publishing, Cambridge, 2005 <iupac.org/wp-content/uploads/2016/07/Red_Book_2005.pdf>

J McMurry, *Organic Chemistry: A Tenth Edition*, OpenStax, Houston, 2023
<openstax.org/details/books/organic-chemistry>

JR Rumble (ed), *CRC Handbook of Chemistry and Physics*, 106th edition, CRC Press

Data for Item 11 was obtained from:

Food Standards Australia New Zealand, *Australian Food Composition Database – Release 3.0*, Food Standards Australia New Zealand <afcd.foodstandards.gov.au/nutrientsearch.aspx> 2023

Data for Items 1 and 15 were obtained from:

National Center for Biotechnology Information, 'Electronegativity in the periodic table of elements', *PubChem*, 2026 <pubchem.ncbi.nlm.nih.gov/periodic-table/electronegativity>

International Union of Pure and Applied Chemistry (IUPAC), *Periodic Table of Elements*, IUPAC <iupac.org/what-we-do/periodic-table-of-elements> 2022

*with relative atomic masses rounded to one decimal place where applicable

Data for Items 16, 17, 19 and 20 were obtained from:

GJ Leigh, et al., *Principles of Chemical Nomenclature: A Guide to IUPAC Recommendations 2011 Edition*, RSC Publishing, UK, 2011 <iupac.org/what-we-do/books/principles>

J McMurry, *Organic Chemistry: A Tenth Edition*, OpenStax, Houston, 2023
<openstax.org/details/books/organic-chemistry>

CL Perrin, et al., 'Glossary of terms used in physical organic chemistry (IUPAC Recommendations 2021)', *Pure and Applied Chemistry*, vol. 94, no. 4, 2022, pp. 353–534
<doi.org/10.1515/pac-2018-1010>

Information for Item 24 was adapted from:

Department of Economic and Social Affairs: Sustainable Development, *The 17 Goals*, United Nations <sdgs.un.org/goals>

PT Anastas and JC Warner, *Green Chemistry: Theory and practice*, Oxford University Press, Oxford, 1998, p. 30

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