

Chemistry

2025 Data Book

Contents	pages
1. Electrochemical series _____	2
2. Chemical relationships _____	3
3. Physical constants and standard values _____	4
4. Unit conversions _____	4
5. Metric prefixes _____	4
6. Acid-base indicators _____	5
7. Colours of selected conjugate redox reagents _____	5
8. Formulas and charges for selected ions _____	6
9. Solubility table _____	8
10. Average bond enthalpies at 25 °C – single bonds _____	9
11. Average bond enthalpies at 25 °C – multiple bonds _____	9
12. Energy content of food groups _____	10
13. Molar enthalpies of combustion _____	10
14. Heats of combustion of selected blended fuels _____	11
15. Heats of combustion of selected biofuels _____	11
16. Periodic table of the elements _____	12
17. Names of selected elements _____	14
18. Representations of organic molecules _____	15
19. Functional group nomenclature in organic chemistry _____	15
20. 2-amino acids (α -amino acids) _____	16
21. Formulas of selected fatty acids _____	18
22. Characteristic ranges for infrared absorption _____	18
23. ^{13}C NMR data _____	19
24. ^1H NMR data _____	20
25. Representations of selected biomolecules _____	22
26. Sustainability _____	22
i. United Nations Sustainable Development Goals _____	22
ii. Green chemistry principles _____	23
iii. Types of economies _____	23

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1. Electrochemical series

Reaction	Standard electrode potential (E^0) in volts at 25 °C
$\text{F}_2(\text{g}) + 2\text{e}^- \rightleftharpoons 2\text{F}^-(\text{aq})$	+2.87
$\text{H}_2\text{O}_2(\text{aq}) + 2\text{H}^+(\text{aq}) + 2\text{e}^- \rightleftharpoons 2\text{H}_2\text{O}(\text{l})$	+1.77
$\text{MnO}_4^-(\text{aq}) + 8\text{H}^+(\text{aq}) + 5\text{e}^- \rightleftharpoons \text{Mn}^{2+}(\text{aq}) + 4\text{H}_2\text{O}(\text{l})$	+1.51
$\text{PbO}_2(\text{s}) + 4\text{H}^+(\text{aq}) + 2\text{e}^- \rightleftharpoons \text{Pb}^{2+}(\text{aq}) + 2\text{H}_2\text{O}(\text{l})$	+1.47
$\text{Cr}_2\text{O}_7^{2-}(\text{aq}) + 14\text{H}^+(\text{aq}) + 6\text{e}^- \rightleftharpoons 2\text{Cr}^{3+}(\text{aq}) + 7\text{H}_2\text{O}(\text{l})$	+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
$\text{Br}_2(\text{l}) + 2\text{e}^- \rightleftharpoons 2\text{Br}^-(\text{aq})$	+1.09
$\text{Ag}^+(\text{aq}) + \text{e}^- \rightleftharpoons \text{Ag}(\text{s})$	+0.80
$\text{Fe}^{3+}(\text{aq}) + \text{e}^- \rightleftharpoons \text{Fe}^{2+}(\text{aq})$	+0.77
$\text{O}_2(\text{g}) + 2\text{H}^+(\text{aq}) + 2\text{e}^- \rightleftharpoons \text{H}_2\text{O}_2(\text{aq})$	+0.68
$\text{I}_2(\text{s}) + 2\text{e}^- \rightleftharpoons 2\text{I}^-(\text{aq})$	+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
$\text{Ni}^{2+}(\text{aq}) + 2\text{e}^- \rightleftharpoons \text{Ni}(\text{s})$	-0.25
$\text{Co}^{2+}(\text{aq}) + 2\text{e}^- \rightleftharpoons \text{Co}(\text{s})$	-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
$\text{Al}^{3+}(\text{aq}) + 3\text{e}^- \rightleftharpoons \text{Al}(\text{s})$	-1.66
$\text{Mg}^{2+}(\text{aq}) + 2\text{e}^- \rightleftharpoons \text{Mg}(\text{s})$	-2.37
$\text{Na}^+(\text{aq}) + \text{e}^- \rightleftharpoons \text{Na}(\text{s})$	-2.71
$\text{Ca}^{2+}(\text{aq}) + 2\text{e}^- \rightleftharpoons \text{Ca}(\text{s})$	-2.87
$\text{K}^+(\text{aq}) + \text{e}^- \rightleftharpoons \text{K}(\text{s})$	-2.93
$\text{Li}^+(\text{aq}) + \text{e}^- \rightleftharpoons \text{Li}(\text{s})$	-3.04

2. Chemical relationships

Name	Formula
amount of substance (number of moles)	$n = \frac{m}{M}; \quad n = cV; \quad n = \frac{V}{V_m}$
universal gas equation	$pV = nRT$
chemical calibration factor (CF) for calorimetry	$CF = \frac{E}{\Delta T}$
electrical calibration factor (CF)	$CF = \frac{VIt}{\Delta T}$
thermal energy transferred	$q = mc\Delta T$
molar enthalpy change	$\Delta H = \frac{q}{n}$
electric charge	$Q = It$
amount of electrons (number of moles)	$n(e^-) = \frac{Q}{F}$
% atom economy	$\frac{\text{molar mass of desired product}}{\text{molar mass of all reactants}} \times \frac{100}{1}$
% yield	$\frac{\text{actual yield}}{\text{theoretical yield}} \times \frac{100}{1}$
equilibrium constant	$K = \frac{[C]^c \times [D]^d \times \dots}{[A]^a \times [B]^b \times \dots}$ for the equation $aA + bB + \dots \rightleftharpoons cC + dD + \dots$

3. 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	$4.18 \text{ kJ kg}^{-1} \text{ K}^{-1}$ or $4.18 \text{ J g}^{-1} \text{ K}^{-1}$
density of water at 25 °C	d	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	$\Delta H_{\text{vap}}(\text{H}_2\text{O})$	$+40.7 \text{ kJ mol}^{-1}$

4. 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 $1 \times 10^3 \text{ mL}$

5. 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}	0.000001
nano (n)	10^{-9}	0.000000001
pico (p)	10^{-12}	0.000000000001

6. 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 → yellow
bromophenol blue	3.0–4.6	yellow → blue
methyl red	4.4–6.2	red → yellow
bromothymol blue	6.0–7.6	yellow → blue
phenol red	6.8–8.4	yellow → red
thymol blue (2nd change)	8.0–9.6	yellow → blue
phenolphthalein	8.3–10.0	colourless → pink

7. Colours of selected conjugate redox reagents

Redox reagent in oxidised state		Redox reagent in reduced state	
Name/formula	Colour	Name/formula	Colour
bromine, Br ₂	brown	bromide ion, Br [−]	colourless
chlorine, Cl ₂	yellow/green	chloride ion, Cl [−]	colourless
copper(II) ion, Cu ²⁺	blue	copper(I) ion, Cu ⁺	red
dichromate ion, Cr ₂ O ₇ ^{2−}	orange	chromium(III) ion, Cr ³⁺	green
iodine, I ₂	brown in aqueous solutions	iodide ion, I [−]	colourless
iron(III) ion, Fe ³⁺	yellow/brown	iron(II) ion, Fe ²⁺	pale green
manganese(IV) dioxide, MnO ₂	black/brown	manganese(II) ion, Mn ²⁺	very pale pink
permanganate ion, MnO ₄ [−]	intense purple	manganese(II) ion, Mn ²⁺	very pale pink

8. 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-		2-		3-	
Name	Formula	Name	Formula	Name	Formula
bromide	Br ⁻	carbonate	CO ₃ ²⁻	citrate	C ₆ H ₅ O ₇ ³⁻
chlorate	ClO ₃ ⁻	chromate	CrO ₄ ²⁻	nitride	N ³⁻
chloride	Cl ⁻	dichromate	Cr ₂ O ₇ ²⁻	phosphate	PO ₄ ³⁻
chlorite	ClO ₂ ⁻	monohydrogen phosphate	HPO ₄ ²⁻		
cyanide	CN ⁻	oxide	O ²⁻		
dihydrogen phosphate	H ₂ PO ₄ ⁻	peroxide	O ₂ ²⁻		
ethanoate	CH ₃ COO ⁻	sulfate	SO ₄ ²⁻		
fluoride	F ⁻	sulfide	S ²⁻		
hydrogen carbonate	HCO ₃ ⁻	sulfite	SO ₃ ²⁻		
hydrogen sulfate	HSO ₄ ⁻	thiosulfate	S ₂ O ₃ ²⁻		
hydrogen sulfide	HS ⁻				
hydrogen sulfite	HSO ₃ ⁻				
hydroxide	OH ⁻				
hypochlorite	ClO ⁻				
iodide	I ⁻				
nitrate	NO ₃ ⁻				
nitrite	NO ₂ ⁻				
perchlorate	ClO ₄ ⁻				
permanganate	MnO ₄ ⁻				

9. Solubility table

Salts	Soluble	Insoluble
sodium	All	None
potassium		
ammonium		
nitrate		
ethanoate		
bromide, chloride, iodide	Most are soluble.	lead(II), silver, CuBr_2 , CuI_2
sulfate	Most are soluble.	barium, calcium, lead(II), silver
carbonate	Group 1 ions, ammonium	Most are insoluble.
phosphate	Group 1 ions, ammonium	Most are insoluble.
hydroxide	Group 1 ions, ammonium	Most are insoluble.

10. Average bond enthalpies at 25 °C – single bonds

ΔH (kJ mol ⁻¹)								
	C	H	O	N	Br	Cl	F	I
C	346	414	358	286	285	324	492	228
H	414	436	463	391	366	431	567	298
O	358	463	144	214	201	206	191	234
N	286	391	214	158		192	278	

11. Average bond enthalpies at 25 °C – multiple bonds

Bond	ΔH (kJ mol ⁻¹)
C=C	614
C≡C	839
C=N	615
C≡N	890
C=O	804
O=O	498
N=N	470
N≡N	945

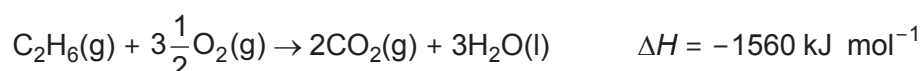
12. Energy content of food groups

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.

Food	Energy content (kJ g ⁻¹)
fats and oils	37
protein	17
carbohydrate	16

13. 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.



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)	-2880
octane	C ₈ H ₁₈ (l)	-5470
methanol	CH ₃ OH(l)	-726
ethanol	C ₂ H ₅ OH(l)	-1370
carbon (graphite)	C(s)	-394
glucose	C ₆ H ₁₂ O ₆ (s)	-2840

14. Heats of combustion of selected blended fuels

Blended fuels are mixtures of compounds with different mixture ratios and, hence, determination of a generic molar enthalpy of combustion is not realistic. The values provided in the following table are typical values for heats of combustion at SLC (25 °C and 100 kPa) with combustion products being CO₂(g) and H₂O(l). Values for heats of combustion will vary due to the composition of the different fuels. 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

15. Heats of combustion of selected biofuels

The following table provides typical values for the heat of combustion of selected biofuels. The values 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	Approx 37
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.

16. Periodic table of the elements

1	2.2																				
H 1.0 hydrogen																					
3	1.0	4	1.6	atomic number														79	2.5	electronegativity value	
Li 6.9 lithium		Be 9.0 beryllium																Au		symbol of element	
																		197.0		relative atomic mass	
																		gold		name of element	
11	0.9	12	1.3																		
Na 23.0 sodium		Mg 24.3 magnesium																			
19	0.8	20	1.0	21	1.4	22	1.5	23	1.6	24	1.7	25	1.6	26	1.8	27	1.9				
K 39.1 potassium		Ca 40.1 calcium		Sc 45.0 scandium		Ti 47.9 titanium		V 50.9 vanadium		Cr 52.0 chromium		Mn 54.9 manganese		Fe 55.8 iron		Co 58.9 cobalt					
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 (98) technetium		Ru 101.1 ruthenium		Rh 102.9 rhodium					
55	0.8	56	0.9			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		57–71 lanthanoids		Hf 178.5 hafnium		Ta 180.9 tantalum		W 183.8 tungsten		Re 186.2 rhenium		Os 190.2 osmium		Ir 192.2 iridium					
87	0.7	88	0.9			104		105		106		107		108		109					
Fr (223) francium		Ra (226) radium		89–103 actinoids		Rf (261) rutherfordium		Db (262) dubnium		Sg (266) seaborgium		Bh (264) bohrium		Hs (267) hassium		Mt (268) meitnerium					
				57		1.1	58	1.1	59	1.1	60	1.1	61		62	1.2	63				
				La 138.9 lanthanum		Ce 140.1 cerium		Pr 140.9 praseodymium		Nd 144.2 neodymium		Pm (145) promethium		Sm 150.4 samarium		Eu 152.0 europium					
				89		1.1	90	1.3	91	1.5	92	1.4	93	1.4	94	1.3	95	1.3			
				Ac (227) actinium		Th 232.0 thorium		Pa 231.0 protactinium		U 238.0 uranium		Np (237) neptunium		Pu (244) plutonium		Am (243) americium					

atomic number

79

electronegativity value

Au

symbol of element

197.0

relative atomic mass

gold

name of element

									2 He 4.0 helium
			5 B 10.8 boron	6 C 12.0 carbon	7 N 14.0 nitrogen	8 O 16.0 oxygen	9 F 19.0 fluorine	10 Ne 20.2 neon	
			13 Al 27.0 aluminium	14 Si 28.1 silicon	15 P 31.0 phosphorus	16 S 32.1 sulfur	17 Cl 35.5 chlorine	18 Ar 39.9 argon	
28 Ni 58.7 nickel	29 Cu 63.5 copper	30 Zn 65.4 zinc	31 Ga 69.7 gallium	32 Ge 72.6 germanium	33 As 74.9 arsenic	34 Se 79.0 selenium	35 Br 79.9 bromine	36 Kr 83.8 krypton	
46 Pd 106.4 palladium	47 Ag 107.9 silver	48 Cd 112.4 cadmium	49 In 114.8 indium	50 Sn 118.7 tin	51 Sb 121.8 antimony	52 Te 127.6 tellurium	53 I 126.9 iodine	54 Xe 131.3 xenon	
78 Pt 195.1 platinum	79 Au 197.0 gold	80 Hg 200.6 mercury	81 Tl 204.4 thallium	82 Pb 207.2 lead	83 Bi 209.0 bismuth	84 Po (210) polonium	85 At (210) astatine	86 Rn (222) radon	
110 Ds (271) darmstadtium	111 Rg (272) roentgenium	112 Cn (285) copernicium	113 Nh (280) nihonium	114 Fl (289) flerovium	115 Mc (289) moscovium	116 Lv (292) livermorium	117 Ts (294) tennessine	118 Og (294) oganeson	

64 Gd 157.3 gadolinium	65 Tb 158.9 terbium	66 Dy 162.5 dysprosium	67 Ho 164.9 holmium	68 Er 167.3 erbium	69 Tm 168.9 thulium	70 Yb 173.1 ytterbium	71 Lu 175.0 lutetium
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96 Cm (247) curium	97 Bk (247) berkelium	98 Cf (251) californium	99 Es (252) einsteinium	100 Fm (257) fermium	101 Md (258) mendelevium	102 No (259) nobelium	103 Lr (262) lawrencium
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Values in brackets indicate the mass number of the longest-lived isotope.

17. Names of selected elements

Element	Symbol	Atomic number	Relative atomic mass (amu)
aluminium	Al	13	27.0
argon	Ar	18	39.9
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

18. Representations of 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	

19. Functional group nomenclature in organic chemistry

The following table shows the priority of functional groups when naming organic compounds that contain more than one functional group.

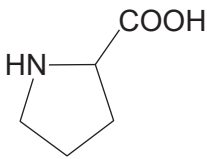
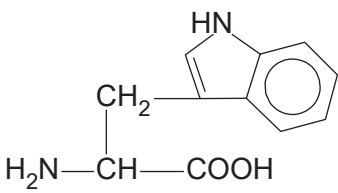
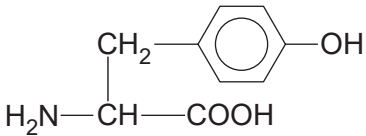
The functional group with the highest priority determines the suffix of the compound.

Class of compound	Functional group name	Prefix	Suffix
carboxylic acid	carboxyl	—	-oic acid
ester	ester	—	-oate
amide	amide	—	-amide
aldehyde	carbonyl	—	-al
ketone	carbonyl	—	-one
alcohol	hydroxy/ hydroxyl	hydroxy-	-ol
amine	amino	amino-	-amine
alkene	alkenyl	—	-ene
halogen	'halo' (i.e. bromo, chloro, fluoro, iodo)	bromo- chloro- fluoro- iodo-	—

20. 2-amino acids (α -amino acids)

The table below 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. They may also be classified as ' α -amino acids', since both the amino group and the carboxyl group are attached to the same carbon atom, known as the alpha carbon. 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	$\begin{array}{c} \text{CH}_3-\text{CH}-\text{CH}_2-\text{CH}_3 \\ \\ \text{H}_2\text{N}-\text{CH}-\text{COOH} \end{array}$
leucine	Leu	$\begin{array}{c} \text{CH}_3-\text{CH}-\text{CH}_3 \\ \\ \text{CH}_2 \\ \\ \text{H}_2\text{N}-\text{CH}-\text{COOH} \end{array}$
lysine	Lys	$\begin{array}{c} \text{CH}_2-\text{CH}_2-\text{CH}_2-\text{CH}_2-\text{NH}_2 \\ \\ \text{H}_2\text{N}-\text{CH}-\text{COOH} \end{array}$
methionine	Met	$\begin{array}{c} \text{CH}_2-\text{CH}_2-\text{S}-\text{CH}_3 \\ \\ \text{H}_2\text{N}-\text{CH}-\text{COOH} \end{array}$
phenylalanine	Phe	$\begin{array}{c} \text{CH}_2-\text{C}_6\text{H}_5 \\ \\ \text{H}_2\text{N}-\text{CH}-\text{COOH} \end{array}$
proline	Pro	
serine	Ser	$\begin{array}{c} \text{CH}_2-\text{OH} \\ \\ \text{H}_2\text{N}-\text{CH}-\text{COOH} \end{array}$
threonine	Thr	$\begin{array}{c} \text{CH}_3-\text{CH}-\text{OH} \\ \\ \text{H}_2\text{N}-\text{CH}-\text{COOH} \end{array}$
tryptophan	Trp	
tyrosine	Tyr	
valine	Val	$\begin{array}{c} \text{CH}_3-\text{CH}-\text{CH}_3 \\ \\ \text{H}_2\text{N}-\text{CH}-\text{COOH} \end{array}$

21. Formulas of selected fatty acids

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

22. Characteristic ranges for infrared absorption

Bond	Wave number (cm^{-1})	Bond	Wave number (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)	1680–1850	N–H (amines and amides)	3300–3500
C=O (esters)	1720–1840		

23. ^{13}C NMR data

Typical ^{13}C shift values relative to TMS = 0

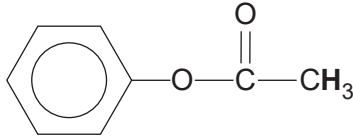
These can differ slightly in different solvents.

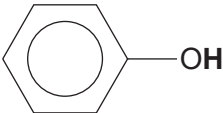
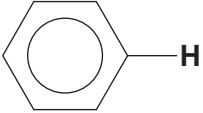
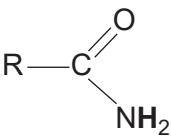
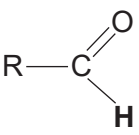
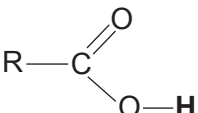
Type of carbon	Chemical shift (ppm)
$\text{R}-\text{CH}_3$	8–25
$\text{R}-\text{CH}_2-\text{R}$	20–45
R_3-CH	40–60
R_4-C	36–45
$\text{R}-\text{CH}_2-\text{X}$	15–80
$\text{R}_3\text{C}-\text{NH}_2$, $\text{R}_3\text{C}-\text{NR}$	35–70
$\text{R}-\text{CH}_2-\text{OH}$	50–90
$\text{R}_2\text{C}=\text{CR}_2$	110–150
arenes $\text{C}_6\text{H}_5-\text{R}$	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
$\text{R}_2\text{C}=\text{O}$	205–220

24. ^1H NMR data

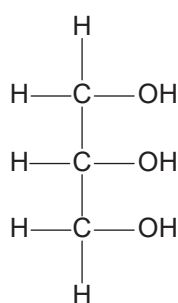
Typical proton shift values relative to TMS = 0

These can differ slightly in different solvents. The shift refers to the proton environment that is indicated in bold letters in the formula.

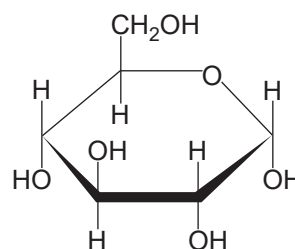
Type of proton	Chemical shift (ppm)
$\text{R}-\text{CH}_3$	0.9–1.0
$\text{R}-\text{CH}_2-\text{R}$	1.3–1.4
$\text{RCH}=\text{CH}-\text{CH}_3$	1.6–1.9
R_3-CH	1.5
$\text{CH}_3-\text{C}(=\text{O})\text{OR}$ or $\text{CH}_3-\text{C}(=\text{O})\text{NHR}$	2.0
$\text{R}-\text{C}(=\text{O})\text{CH}_3$	2.1–2.7
$\text{R}-\text{CH}_2-\text{X}$ (X = F, Cl, Br or I)	3.0–4.5
$\text{R}-\text{CH}_2-\text{OH}$, $\text{R}_2-\text{CH}-\text{OH}$	3.3–4.5
$\text{R}-\text{C}(=\text{O})\text{NHCH}_2\text{R}$	3.2
$\text{R}-\text{O}-\text{CH}_3$ or $\text{R}-\text{O}-\text{CH}_2\text{R}$	3.3–3.7
	2.3
$\text{R}-\text{C}(=\text{O})\text{OCH}_2\text{R}$	3.7–4.8
$\text{R}-\text{O}-\text{H}$	1–6 (varies considerably under different conditions)
$\text{R}-\text{NH}_2$	1–5
$\text{RHC}=\text{CHR}$	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

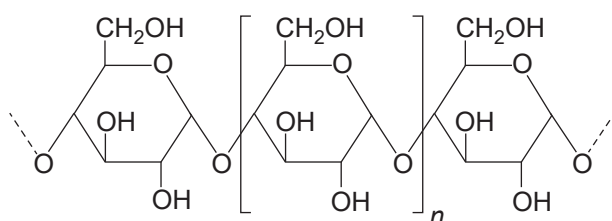
25. Representations of selected biomolecules



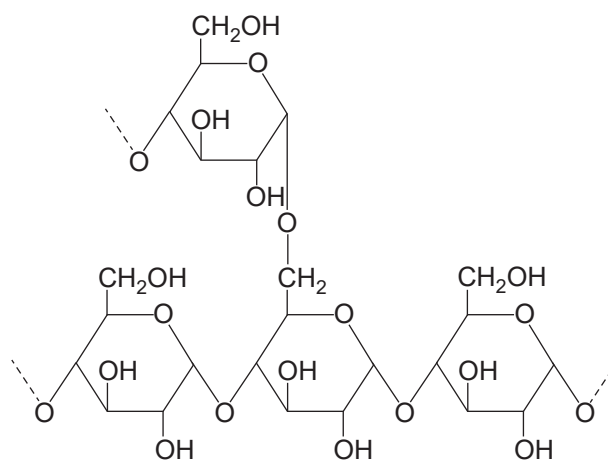
glycerol



α -D-glucose



amylose (starch)



amylopectin (starch)

26. Sustainability

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

Source: Adapted from 'The 17 Goals',
Department of Economic and Social Affairs,
Sustainable Development, United Nations
<<https://sdgs.un.org/goals>>

ii. Green chemistry principles

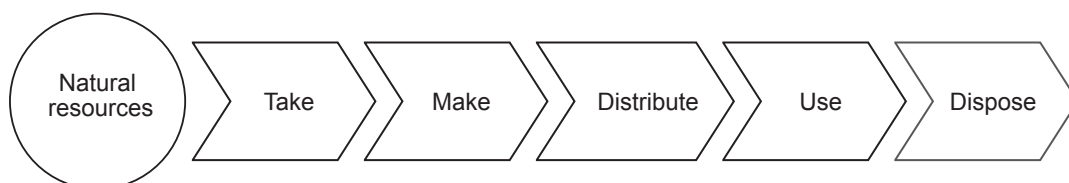
The following seven green chemistry principles are relevant to VCE Chemistry:

- 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.

Source: Adapted from PT Anastas and JC Warner,
Green Chemistry: Theory and Practice, Oxford University Press, New York, 1998, p.30

iii. Types of economies

Linear



Circular

