Chemistry

Data Book

2024 VCE Examination

Contents pages

VICTORIAN CURRICULUM AND ASSESSMENT AUTHORITY

VICTORIA State Government

1. Electrochemical series

Reaction	Standard electrode potential (E^0) in volts at 25 °C
$F_2(g) + 2e^- \rightleftharpoons 2F^-(aq)$	+2.87
$H_2O_2(aq) + 2H^+(aq) + 2e^- \rightleftharpoons 2H_2O(l)$	+1.77
$MnO_4^-(aq) + 8H^+(aq) + 5e^- \rightleftharpoons Mn^{2+}(aq) + 4H_2O(l)$	+1.51
$PbO_2(s) + 4H^+(aq) + 2e^- \rightleftharpoons Pb^{2+}(aq) + 2H_2O(l)$	+1.47
$Cr_2O_7^{2-}(aq) + 14H^+(aq) + 6e^- \rightleftharpoons 2Cr^{3+}(aq) + 7H_2O(l)$	+1.36
$Cl_2(g) + 2e^- \rightleftharpoons 2Cl^-(aq)$	+1.36
$O_2(g) + 4H^+(aq) + 4e^- \rightleftharpoons 2H_2O(l)$	+1.23
$Br_2(l) + 2e^- \rightleftharpoons 2Br^-(aq)$	+1.09
$Ag^+(aq) + e^- \rightleftharpoons Ag(s)$	+0.80
$Fe^{3+}(aq) + e^- \rightleftharpoons Fe^{2+}(aq)$	+0.77
$O_2(g) + 2H^+(aq) + 2e^- \rightleftharpoons H_2O_2(aq)$	+0.68
$I_2(s) + 2e^- \rightleftharpoons 2I^-(aq)$	+0.54
$O_2(g) + 2H_2O(l) + 4e^- \rightleftharpoons 4OH^-(aq)$	+0.40
$Cu^{2+}(aq) + 2e^- \rightleftharpoons Cu(s)$	+0.34
$Sn^{4+}(aq) + 2e^- \rightleftharpoons Sn^{2+}(aq)$	+0.15
$2H^+(aq) + 2e^- \rightleftharpoons H_2(g)$	0.00
$Pb^{2+}(aq) + 2e^- \rightleftharpoons Pb(s)$	−0.13
$Sn^{2+}(aq) + 2e^- \rightleftharpoons Sn(s)$	−0.14
$Ni^{2+}(aq) + 2e^- \rightleftharpoons Ni(s)$	−0.25
$Co^{2+}(aq) + 2e^- \rightleftharpoons Co(s)$	−0.28
$Fe^{2+}(aq) + 2e^- \rightleftharpoons Fe(s)$	−0.44
$Zn^{2+}(aq) + 2e^- \rightleftharpoons Zn(s)$	−0.76
$2H_2O(l) + 2e^- \rightleftharpoons H_2(g) + 2OH^-(aq)$	−0.83
$Mn^{2+}(aq) + 2e^- \rightleftharpoons Mn(s)$	−1.18
$Al^{3+}(aq) + 3e^- \rightleftharpoons Al(s)$	−1.66
$Mg^{2+}(aq) + 2e^- \rightleftharpoons Mg(s)$	−2.37
$Na^+(aq) + e^- \rightleftharpoons Na(s)$	−2.71
$Ca^{2+}(aq) + 2e^- \rightleftharpoons Ca(s)$	−2.87
$K^+(aq) + e^- \rightleftharpoons K(s)$	−2.93
$Li^+(aq) + e^- \rightleftharpoons Li(s)$	−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	$\text{CF} = \frac{E}{\Delta T}$
electrical calibration factor (CF)	$\text{CF} = \frac{VIt}{\Delta T}$
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	$K = \frac{[C]^c \times [D]^d \times \ldots}{[A]^a \times [B]^b \times \ldots}$ for the equation $aA + bB + \ldots \rightleftharpoons cC + dD + \ldots$

3. Physical constants and standard values

Name	Symbol	Value
Avogadro constant	N_A or L	6.02×10^{23} mol^{-1}
Faraday constant	F	96 500 C mol^{-1}
molar gas constant	R	8.31 J mol^{-1} 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 kJ kg^{-1} K^{-1} or 4.18 J g^{-1} K^{-1}
density of water at 25 °C	d	1.0 g mL^{-1}
molar latent heat of vaporisation of water at 25 °C	$\Delta H_{vap}(H_2O)$	+44.0 kJ mol^{-1}
molar latent heat of vaporisation of water at 100 °C	$\Delta H_{vap}(H_2O)$	+40.7 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 1×10^{-3} m^3 or 1×10^3 cm^3 or 1×10^3 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, $Cr_2O_7^{2-}$	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_3O^+	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	$C_6H_5O_7^{3-}$
chlorate	ClO_3^-	chromate	CrO_4^{2-}	nitride	N^{3-}
chloride	Cl^-	dichromate	$Cr_2O_7^{2-}$	phosphate	PO_4^{3-}
chlorite	ClO_2^-	monohydrogen phosphate	HPO_4^{2-}		
cyanide	CN^-	oxide	O^{2-}		
dihydrogen phosphate	$H_2PO_4^-$	peroxide	O_2^{2-}		
ethanoate	CH_3COO^-	sulfate	SO_4^{2-}		
fluoride	F^-	sulfide	S^{2-}		
hydrogen carbonate	HCO_3^-	sulfite	SO_3^{2-}		
hydrogen sulfate	HSO_4^-	thiosulfate	$S_2O_3^{2-}$		
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 $CO_2(g)$ and $H_2O(l)$. 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.

$$C_2H_6(g) + 3\frac{1}{2}O_2(g) \rightarrow 2CO_2(g) + 3H_2O(l) \qquad \Delta H = -1560 \text{ kJ mol}^{-1}$$

Fuel	Formula	Molar enthalpy of combustion (kJ mol^{-1})
hydrogen	$H_2(g)$	−286
methane	$CH_4(g)$	−890
ethane	$C_2H_6(g)$	−1560
propane	$C_3H_8(g)$	−2220
butane	$C_4H_{10}(g)$	−2880
octane	$C_8H_{18}(l)$	−5470
methanol	$CH_3OH(l)$	−726
ethanol	$C_2H_5OH(l)$	−1370
carbon (graphite)	C(s)	−394
glucose	$C_6H_{12}O_6(s)$	−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 $CO_2(g)$ and $H_2O(l)$. 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.

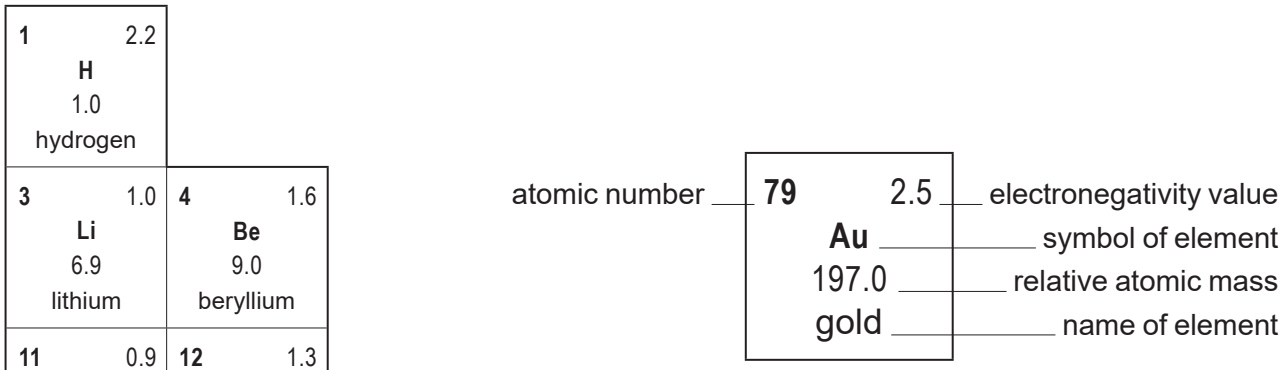
Fuel	State	Heat of combustion ($kJ\ g^{-1}$)	Heat of combustion ($kJ\ mL^{-1}$)
diesel	liquid	45	37
kerosene	liquid	46	37
natural gas	gas	54	0.035
petrol	liquid	45	34

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 **Li** 6.9 lithium	**4** 1.6 **Be** 9.0 beryllium							
11 0.9 **Na** 23.0 sodium	**12** 1.3 **Mg** 24.3 magnesium							
19 0.8 **K** 39.1 potassium	**20** 1.0 **Ca** 40.1 calcium	**21** 1.4 **Sc** 45.0 scandium	**22** 1.5 **Ti** 47.9 titanium	**23** 1.6 **V** 50.9 vanadium	**24** 1.7 **Cr** 52.0 chromium	**25** 1.6 **Mn** 54.9 manganese	**26** 1.8 **Fe** 55.8 iron	**27** 1.9 **Co** 58.9 cobalt
37 0.8 **Rb** 85.5 rubidium	**38** 1.0 **Sr** 87.6 strontium	**39** 1.2 **Y** 88.9 yttrium	**40** 1.3 **Zr** 91.2 zirconium	**41** 1.6 **Nb** 92.9 niobium	**42** 2.2 **Mo** 96.0 molybdenum	**43** 1.9 **Tc** (98) technetium	**44** 2.2 **Ru** 101.1 ruthenium	**45** 2.3 **Rh** 102.9 rhodium
55 0.8 **Cs** 132.9 caesium	**56** 0.9 **Ba** 137.3 barium	**57–71** lanthanoids	**72** 1.3 **Hf** 178.5 hafnium	**73** 1.5 **Ta** 180.9 tantalum	**74** 2.4 **W** 183.8 tungsten	**75** 1.9 **Re** 186.2 rhenium	**76** 2.2 **Os** 190.2 osmium	**77** 2.2 **Ir** 192.2 iridium
87 0.7 **Fr** (223) francium	**88** 0.9 **Ra** (226) radium	**89–103** actinoids	**104** **Rf** (261) rutherfordium	**105** **Db** (262) dubnium	**106** **Sg** (266) seaborgium	**107** **Bh** (264) bohrium	**108** **Hs** (267) hassium	**109** **Mt** (268) meitnerium

57 1.1 **La** 138.9 lanthanum	**58** 1.1 **Ce** 140.1 cerium	**59** 1.1 **Pr** 140.9 praseodymium	**60** 1.1 **Nd** 144.2 neodymium	**61** **Pm** (145) promethium	**62** 1.2 **Sm** 150.4 samarium	**63** **Eu** 152.0 europium
89 1.1 **Ac** (227) actinium	**90** 1.3 **Th** 232.0 thorium	**91** 1.5 **Pa** 231.0 protactinium	**92** 1.4 **U** 238.0 uranium	**93** 1.4 **Np** (237) neptunium	**94** 1.3 **Pu** (244) plutonium	**95** 1.3 **Am** (243) americium

								2 **He** 4.0 **helium**
			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** 39.9 argon
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** (210) polonium	**85** 2.2 **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) oganesson

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	**7.0** **Yb** 173.1 ytterbium	**71** 1.3 **Lu** 175.0 lutetium

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

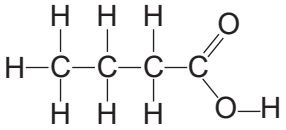
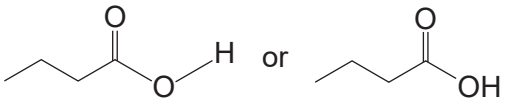
Values in brackets indicate the mass number of the longest-lived isotope.

17. Names of selected elements

Element	Symbol	Atomic number	Relative atomic mass (amu)	Element	Symbol	Atomic number	Relative atomic mass (amu)
aluminium	Al	13	27.0	magnesium	Mg	12	24.3
argon	Ar	18	39.9	manganese	Mn	25	54.9
arsenic	As	33	74.9	mercury	Hg	80	200.6
barium	Ba	56	137.3	neon	Ne	10	20.2
beryllium	Be	4	9.0	nickel	Ni	28	58.7
boron	B	5	10.8	nitrogen	N	7	14.0
bromine	Br	35	79.9	oxygen	O	8	16.0
cadmium	Cd	48	112.4	phosphorus	P	15	31.0
caesium	Cs	55	132.9	platinum	Pt	78	195.1
calcium	Ca	20	40.1	potassium	K	19	39.1
carbon	C	6	12.0	rubidium	Rb	37	85.5
chlorine	Cl	17	35.5	scandium	Sc	21	45.0
chromium	Cr	24	52.0	selenium	Se	34	79.0
cobalt	Co	27	58.9	silicon	Si	14	28.1
copper	Cu	29	63.5	silver	Ag	47	107.9
fluorine	F	9	19.0	sodium	Na	11	23.0
gallium	Ga	31	69.7	strontium	Sr	38	87.6
germanium	Ge	32	72.6	sulfur	S	16	32.1
gold	Au	79	197.0	tin	Sn	50	118.7
helium	He	2	4.0	titanium	Ti	22	47.9
hydrogen	H	1	1.0	tungsten	W	74	183.8
iodine	I	53	126.9	vanadium	V	23	50.9
iron	Fe	26	55.8	xenon	Xe	54	131.3
krypton	Kr	36	83.8	yttrium	Y	39	88.9
lead	Pb	82	207.2	zinc	Zn	30	65.4
lithium	Li	3	6.9	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	

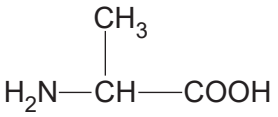
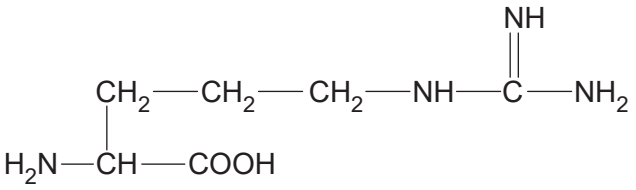
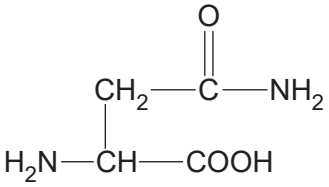
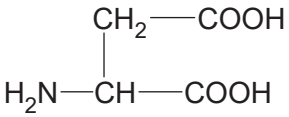
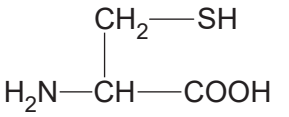
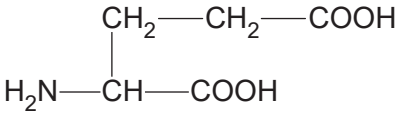
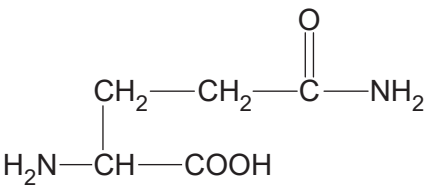
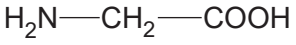
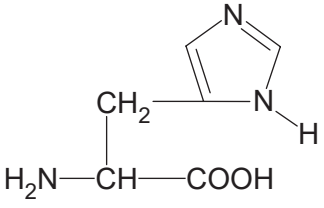
19. Functional group nomenclature in organic chemistry

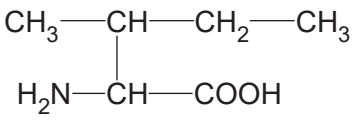
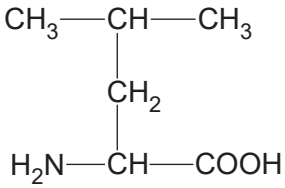
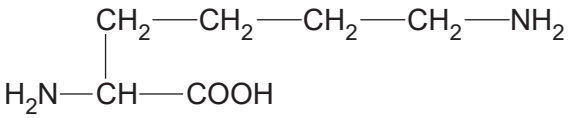
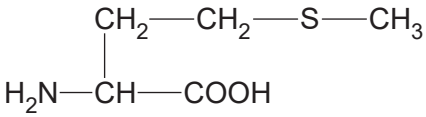
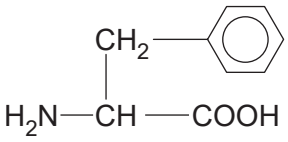
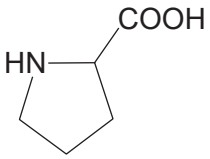
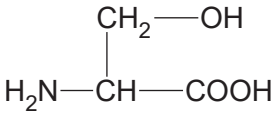
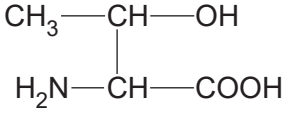
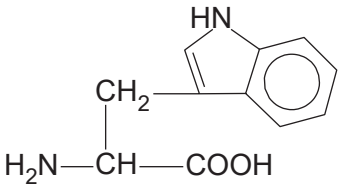
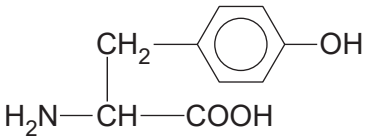
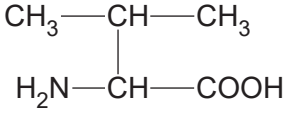
The following table shows the priority of functional groups when naming organic compounds that contain more than one functional group. The functional group with the highest priority determines the suffix of the compound.

Class of compound	Functional group name	Prefix	Suffix
carboxylic acid	carboxyl	–	-oic acid
ester	ester	–	-oate
amide	amide	–	-amide
aldehyde	aldehyde	–	-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 (-NH_2) is attached to the second carbon atom in the carbon chain, numbered from the carboxyl (-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	
arginine	Arg	
asparagine	Asn	
aspartic acid	Asp	
cysteine	Cys	
glutamic acid	Glu	
glutamine	Gln	
glycine	Gly	
histidine	His	

Name	Symbol	Structure
isoleucine	Ile	
leucine	Leu	
lysine	Lys	
methionine	Met	
phenylalanine	Phe	
proline	Pro	
serine	Ser	
threonine	Thr	
tryptophan	Trp	
tyrosine	Tyr	
valine	Val	

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	$C_{20}H_{32}O_2$	$CH_3(CH_2)_4(CH=CHCH_2)_3CH=CH(CH_2)_3COOH$

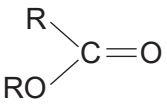
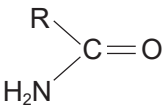
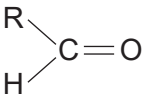
22. Characteristic ranges for infrared absorption

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

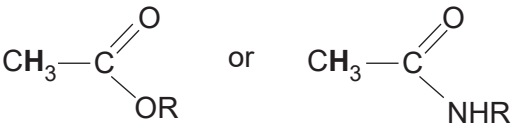
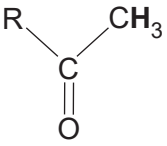
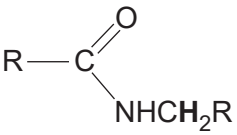
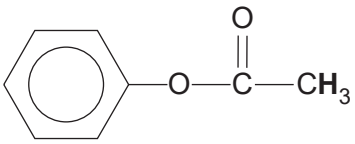
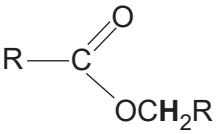
These can differ slightly in different solvents.

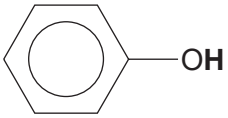
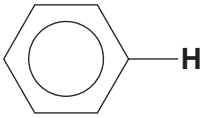
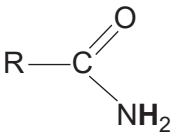
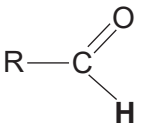
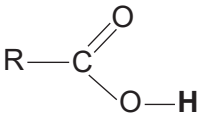
Type of carbon	Chemical shift (ppm)
$R–CH_3$	8–25
$R–CH_2–R$	20–45
$R_3–CH$	40–60
$R_4–C$	36–45
$R–CH_2–X$	15–80
$R_3C–NH_2$, $R_3C–NR$	35–70
$R–CH_2–OH$	50–90
$R_2C=CR_2$	110–150
arenes $C_6H_5–R$	110–150
RCOOH	160–185
	165–175
	165–185
	190–200
$R_2C=O$	205–220

24. ^{1}H NMR data

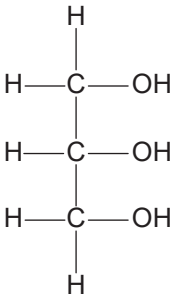
Typical proton shift values relative to TMS = 0

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

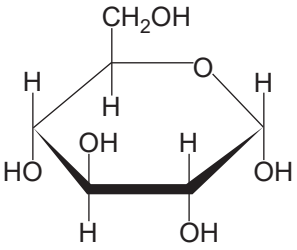
Type of proton	Chemical shift (ppm)
R–C**H**$_3$	0.9–1.0
R–C**H**$_2$–R	1.3–1.4
RCH=CH–C**H**$_3$	1.6–1.9
R$_3$–C**H**	1.5
	2.0
	2.1–2.7
R–C**H**$_2$–X (X = F, Cl, Br or I)	3.0–4.5
R–C**H**$_2$–OH, R$_2$–C**H**–OH	3.3–4.5
	3.2
R—O—C**H**$_3$ or R—O—C**H**$_2$R	3.3–3.7
	2.3
	3.7–4.8
R–O–**H**	1–6 (varies considerably under different conditions)
R–N**H**$_2$	1–5
RHC=C**H**R	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

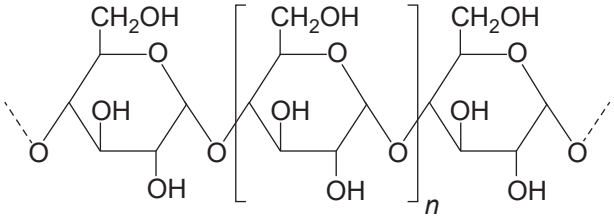
25. Representations of selected biomolecules



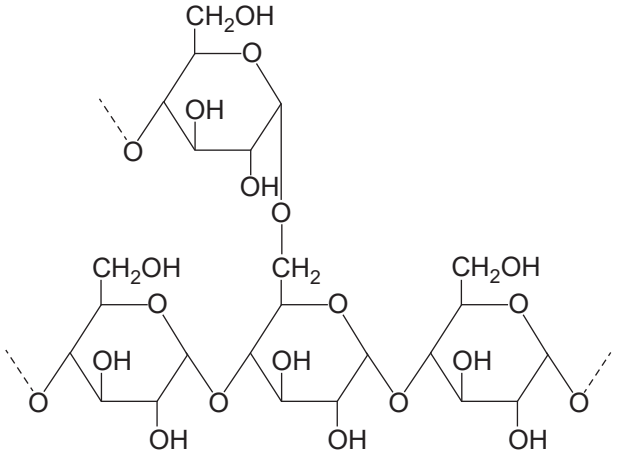
glycerol



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

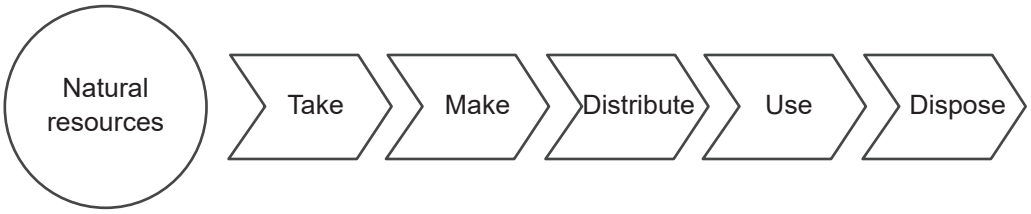
ii. Green chemistry principles

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

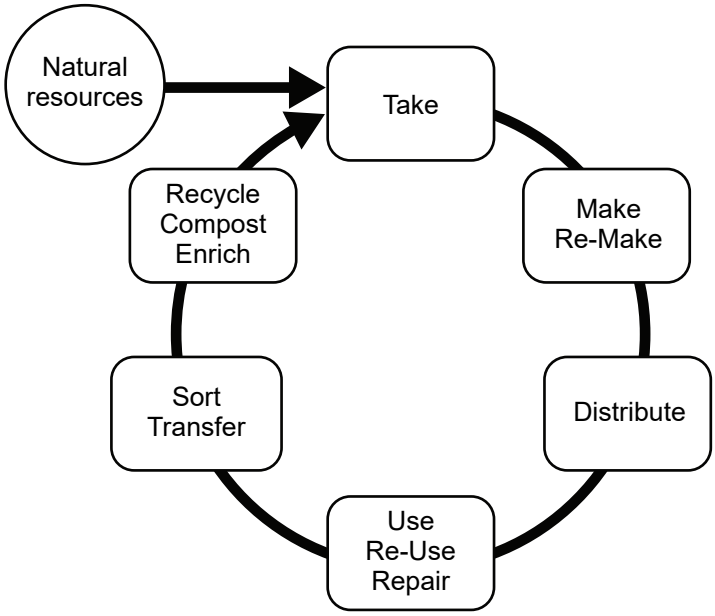
- Atom economy: Processes/pathways should be designed to maximise incorporation of all reactant materials used in the process into the final product.
- Catalysis: Catalysts should be selected to generate the same desired product(s) with less waste and using less energy and reagents in reaction processes/pathways.
- 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



End of Chemistry Data Book