VICTORIAN CURRICULUM AND ASSESSMENT AUTHORITY

Victorian Certificate of Education
Year

2021 EDITION

CHEMISTRY

Written examination

ANNOTATED

DATA BOOK

Instructions

This data book is provided for your reference.
A question and answer book is provided with this data book.

Students are NOT permitted to bring mobile phones and/or any other unauthorised electronic devices into the examination room.

December 2020

Table of contents

1. Periodic table of the elements

ELECTRONEGATIVITY

1ST IONISATION ENERGY

METALLIC CHARACTER

ATOMIC RADIUS

1+ IONS

2+ IONS

INCREASING CORE CHARGE

INCREASING SHIELDING

CAN FORM HYDROGEN BONDS

atomic number / relative atomic mass / symbol of element / name of element

1 H 1.0 hydrogen																	2 He 4.0 helium
3 Li 6.9 lithium	4 Be 9.0 beryllium											5 B 10.8 boron	6 C 12.0 carbon	7 N–H 14.0 nitrogen	8 O–H 16.0 oxygen	9 F–H 19.0 fluorine	10 Ne 20.2 neon
11 Na 23.0 sodium	12 Mg 24.3 magnesium											13 Al 27.0 aluminium	14 Si 28.1 silicon	15 P 31.0 phosphorus	16 S 32.1 sulfur	17 Cl (g) 35.5 chlorine	18 Ar 39.9 argon
19 K 39.1 potassium	20 Ca 40.1 calcium	21 Sc 45.0 scandium	22 Ti 47.9 titanium	23 V 50.9 vanadium	24 Cr 52.0 chromium	25 Mn 54.9 manganese	26 Fe 55.8 iron	27 Co 58.9 cobalt	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 (l) 79.9 bromine	36 Kr 83.8 krypton
37 Rb 85.5 rubidium	38 Sr 87.6 strontium	39 Y 88.9 yttrium	40 Zr 91.2 zirconium	41 Nb 92.9 niobium	42 Mo 96.0 molybdenum	43 Tc (98) technetium	44 Ru 101.1 ruthenium	45 Rh 102.9 rhodium	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 (s) 126.9 iodine	54 Xe 131.3 xenon
55 Cs 132.9 caesium	56 Ba 137.3 barium	57–71 lanthanoids	72 Hf 178.5 hafnium	73 Ta 180.9 tantalum	74 W 183.8 tungsten	75 Re 186.2 rhenium	76 Os 190.2 osmium	77 Ir 192.2 iridium	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
87 Fr (223) francium	88 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	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

$4s^1 3d^5$ ← EXCEPTIONS TO AUFBAU RULE → $4s^1 3d^{10}$

NON-METALS

due to INCREASING DISPERSION FORCES

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

ALL ELEMENTS AFTER URANIUM ARE ARTIFICIAL

The value in brackets indicates the mass number of the longest-lived isotope.

2. Electrochemical series

Reaction (OXIDANTS ⇌ REDUCTANTS)	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
$Au^+(aq) + e^- \rightleftharpoons Au(s)$	+1.68
$Cl_2(g) + 2e^- \rightleftharpoons 2Cl^-(aq)$	+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
$S(s) + 2H^+(aq) + 2e^- \rightleftharpoons H_2S(g)$	+0.14
$2H^+(aq) + 2e^- \rightleftharpoons H_2(g)$	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
$Cd^{2+}(aq) + 2e^- \rightleftharpoons Cd(s)$	–0.40
$Fe^{2+}(aq) + 2e^- \rightleftharpoons Fe(s)$	–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

STONGEST OXIDANT

STRONGEST REDUCTANT

MOST REACTIVE METAL ON THIS LIST

STANDARD CONDITIONS
- 1 atm pressure
- 1 M conc
- 25°C temp

THESE TWO HALF-EQUATIONS SWAP AT ≥2M

SOC reacts with SRA

Strongest oxidant at the cathode

Strongest reductant at the anode

$KNO_3(aq)$ → K^+ + NO_3^-

STANDARD HYDROGEN ELECTRODE (S.H.E.)

ALL THESE ELECTRODE POTENTIALS CHANGE WHEN AT NON-STANDARD CONDITIONS.

THESE METALS CAN ONLY FORM FROM A **MOLTEN** ELECTROLYTE

3. Chemical relationships

Name	Formula
number of moles of a substance	$n = \frac{m}{M}; \quad n = cV; \quad n = \frac{V}{V_m}$
universal gas equation	$pV = nRT$ also : $p = cRT$
calibration factor (CF) for bomb calorimetry	$\text{CF} = \frac{VIt}{\Delta T}$ DON'T ADD 273 TO ΔT
heat energy released in the combustion of a fuel	$q = mc\Delta T$ (J)
enthalpy of combustion	$\Delta H = \frac{q}{n}$ (kJ) IF THERE'S ΔH IN THE EQUATION THEN q HAS UNITS kJ... otherwise, J
electric charge	$Q = It$
number of moles of electrons	$n(e^-) = \frac{Q}{F}$
% atom economy	$\frac{\text{molar mass of desired product}}{\text{molar mass of all reactants}} \times \frac{100}{1}$
% yield	$\frac{\text{actual yield}}{\text{theoretical yield}} \times \frac{100}{1}$

4. Physical constants and standard values

Name	Symbol	Value
Avogadro constant	N_A ~~or L~~	6.02×10^{23} mol^{-1}
charge on one electron (elementary charge)	e	-1.60×10^{-19} C
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	997 kg m^{-3} or 0.997 g mL^{-1}

NUMBER OF PARTICLES

$$n = \frac{N}{N_A}$$

DILUTION FORMULA

$$C_1V_1 = C_2V_2$$

AQUEOUS MIXTURES FORMULA

$$C_1V_1 + C_2V_2 = C_3V_3$$

GAS FORMULA

$$\frac{P_1V_1}{n_1T_1} = \frac{P_2V_2}{n_2T_2}$$

DENSITY FORMULA

$$d = \frac{m}{V}$$

TURN OVER

5. Unit conversions

Measured value	Conversion
0 °C	273 K
100 kPa	750 mm Hg or 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

6. Metric (including SI) prefixes

Metric (including SI) 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

IN CALCULATIONS, PREFIXES AND VALUES ARE INTERCHANGEABLE, for example:

$3\ GL = 3 \times 10^9\ L$

pH FORMULAE

$pH = -\log_{10}[H^+]$

$[H^+] = 10^{-pH}$

$[H^+] = \frac{10^{-14}}{[OH^-]}$

$[OH^-] = \frac{10^{-14}}{[H^+]}$

ONLY TRUE WHEN THE SOLUTION IS AT 25°C

$[H^+] = [H_3O^+]$

7. Acid-base indicators

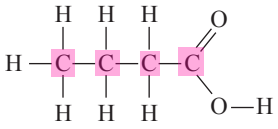
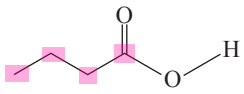
Name	pH range	Colour change from lower pH to higher pH in range
thymol blue (1st change)	1.2–2.8	red → yellow
methyl orange	3.1–4.4	red → yellow
bromophenol blue	3.0–4.6	yellow → blue
methyl red	4.4–6.2	red → yellow
bromothymol blue	6.0–7.6	yellow → blue
phenol red	6.8–8.4	yellow → red
thymol blue (2nd change)	8.0–9.6	yellow → blue
phenolphthalein	8.3–10.0	colourless → pink

DON'T CONFUSE THESE TWO!

In pure water: $[H^+] = [OH^-]$ and is always neutral even if the pH isn't 7.

8. 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	 ALWAYS DRAW ALL ATOMS & ALL BONDS
semi-structural (condensed) formula	$CH_3CH_2CH_2COOH$ or $CH_3(CH_2)_2COOH$
skeletal structure	 CORNERS & ENDS WITHOUT A LETTER ARE CARBON ATOMS

9. Formulas of some fatty acids

Name	Formula	N(C=C)	Semi-structural formula
lauric acid	$C_{11}H_{23}COOH$	0	$CH_3(CH_2)_{10}COOH$
myristic acid	$C_{13}H_{27}COOH$	0	$CH_3(CH_2)_{12}COOH$
palmitic acid	$C_{15}H_{31}COOH$	0	$CH_3(CH_2)_{14}COOH$
palmitoleic acid	$C_{15}H_{29}COOH$	1	$CH_3(CH_2)_4CH_2CH{=}CHCH_2\,(CH_2)_5CH_2COOH$
stearic acid	$C_{17}H_{35}COOH$	0	$CH_3(CH_2)_{16}COOH$
oleic acid	$C_{17}H_{33}COOH$	1	$CH_3(CH_2)_7CH{=}CH(CH_2)_7COOH$
linoleic acid	$C_{17}H_{31}COOH$	2	$CH_3(CH_2)_4(CH{=}CHCH_2)_2(CH_2)_6COOH$
linolenic acid	$C_{17}H_{29}COOH$	3	$CH_3CH_2(CH{=}CHCH_2)_3(CH_2)_6COOH$
arachidic acid	$C_{19}H_{39}COOH$	0	$CH_3(CH_2)_{17}CH_2COOH$
arachidonic acid	$C_{19}H_{31}COOH$	4	$CH_3(CH_2)_4(CH{=}CHCH_2)_3CH{=}CH(CH_2)_3COOH$

TO FIND N(C=C) IN A FATTY ACID TAIL, USE THIS FORMULA:

$$N(C{=}C) = C - \frac{H-1}{2}$$

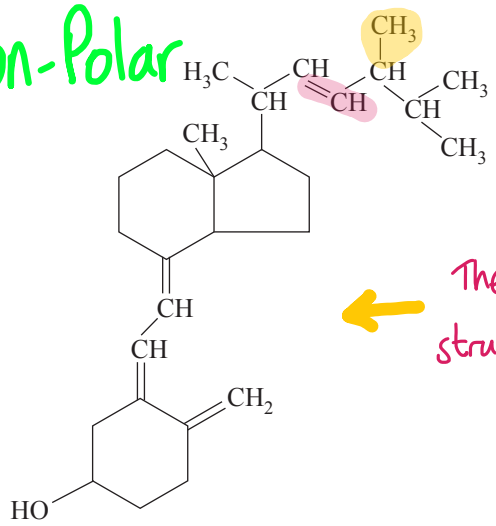
E.G. ARACHIDONIC ACID $C_{19}H_{31}COOH$ HAS **4** C=C BONDS:

$$N(C{=}C) = 19 - \frac{31-1}{2} = 4$$

THERE ARE NO BENZENE RINGS ON THIS PAGE

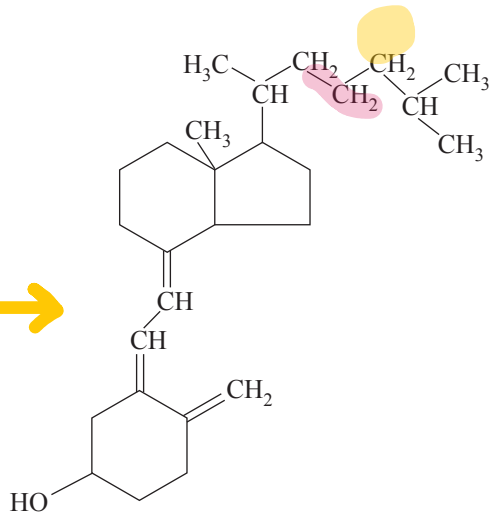
10 Formulas of some biochemical compounds

Non-Polar



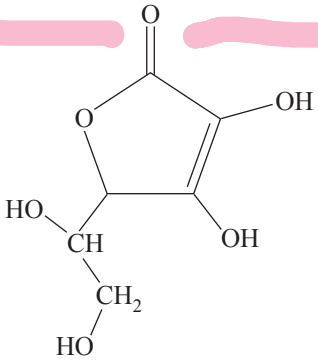
vitamin D_2 (ergocalciferol)

These are NOT structural isomers

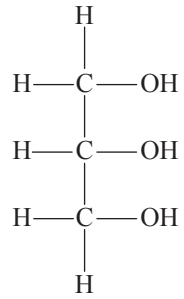


vitamin D_3 (cholecalciferol)

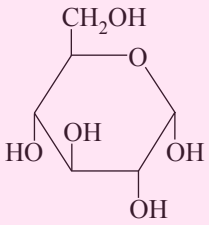
Polar



vitamin C (ascorbic acid)

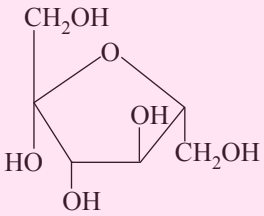


glycerol

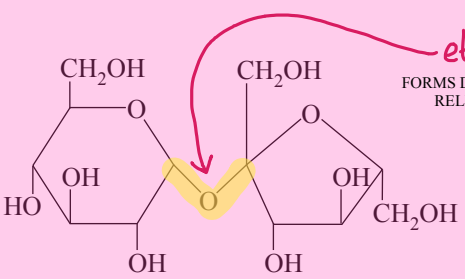


α-glucose

monosaccharides
$C_6H_{12}O_6$
$M_r = 180$



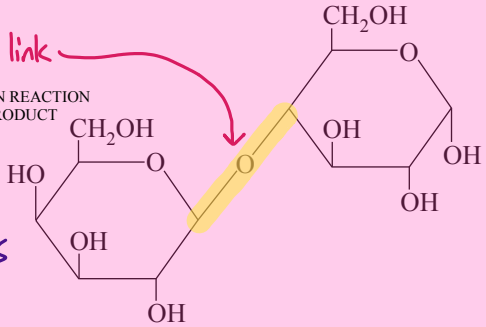
β-fructose



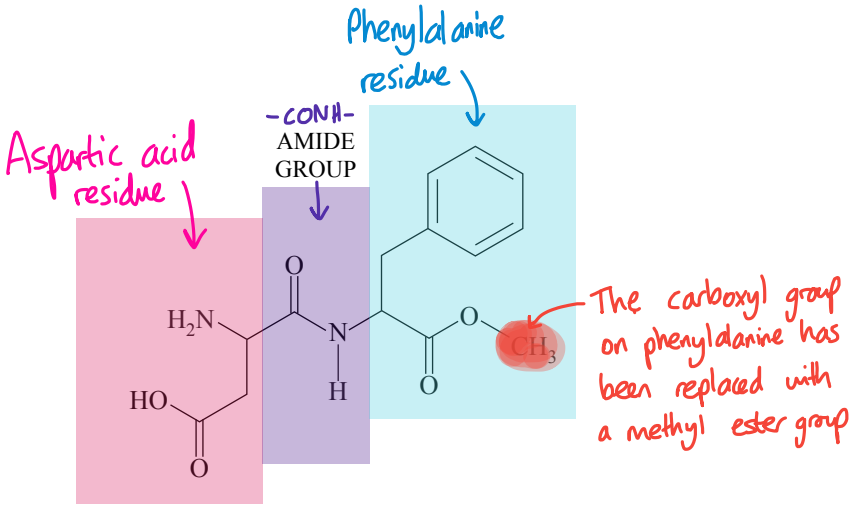
sucrose

ether / glycosidic link
FORMS DURING CONDENSATION REACTION
RELEASING H_2O AS A BY-PRODUCT

disaccharides
$C_{12}H_{22}O_{11}$
$M_r = 342$

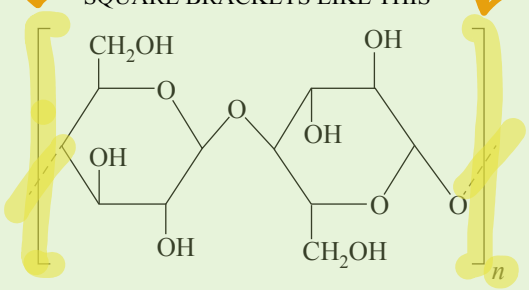


α-lactose

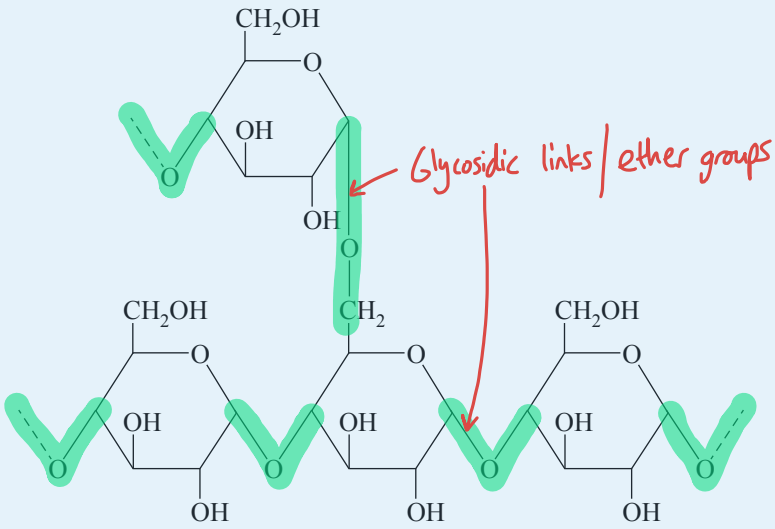


aspartame

WHEN DRAWING A POLYMER, ALWAYS DRAW BONDS THROUGH SQUARE BRACKETS LIKE THIS

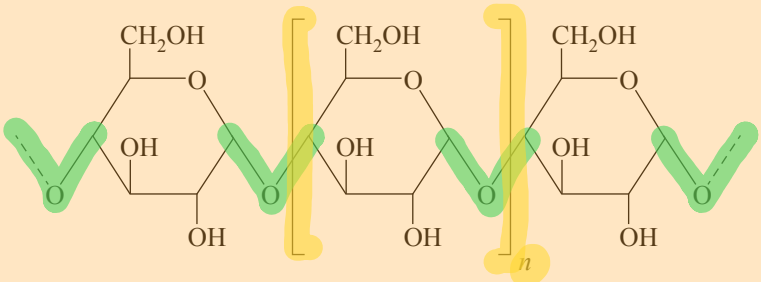


cellulose CONSISTS OF β-glucose units



CONSISTS OF α-glucose units

more soluble amylopectin (starch) Branched



CONSISTS OF α-glucose units

less soluble amylose (starch) Straight

11. Heats of combustion of common fuels

The heats of combustion in the following table are calculated at SLC (25 °C and 100 kPa) with combustion products being CO_2 and H_2O. Heat of combustion may be defined as the heat energy released when a specified amount of a substance burns completely in oxygen and is, therefore, reported as a positive value, indicating a magnitude. Enthalpy of combustion, ΔH, for the substances in this table would be reported as negative values, indicating the exothermic nature of the combustion reaction.

very useful info

Fuel	Formula	State	Heat of combustion (kJ g^{-1})	Molar heat of combustion (kJ mol^{-1})
hydrogen	H_2	gas	141	282
methane	CH_4	gas	55.6	890
ethane	C_2H_6	gas	51.9	1560
propane	C_3H_8	gas	50.5	2220
butane	C_4H_{10}	gas	49.7	2880
octane	C_8H_{18}	liquid	47.9	5460
ethyne (acetylene)	C_2H_2	gas	49.9	1300
methanol	CH_3OH	liquid	22.7	726
ethanol	C_2H_5OH	liquid	29.6	1360

REMEMBER: NOTHING AQUEOUS COMBUSTS! (ACCORDING TO THE VCAA)

12. Heats of combustion of common 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 and H_2O. Values for heats of combustion will vary depending on the source and composition of the fuel.

Fuel	State	Heat of combustion (kJ g^{-1})
kerosene	liquid	46.2
diesel	liquid	45.0
natural gas	gas	54.0

These three fuels are mixtures

QUICKEST WAY TO BALANCE ANY COMBUSTION EQUATION:

C then H then O

AND USE FRACTIONS WHERE NEEDED
e.g. ½ or ¼

13. Energy content of food groups

Food	Heat of combustion (kJ g^{-1})	DIGESTED BY
fats and oils	37	pancreatic lipase
protein	17	pepsin/trypsin (stomach)
carbohydrate	16	amylase (saliva)

Always copy bond names EXACTLY

14. Characteristic ranges for infra-red absorption

Bond	Wave number (cm^{-1})	Bond	Wave number (cm^{-1})
C–Cl (chloroalkanes)	600–800	C=O (ketones)	1680–1850
C–O (alcohols, esters, ethers)	1050–1410	C=O (esters)	1720–1840
C=C (alkenes)	1620–1680	C–H (alkanes, alkenes, arenes)	2850–3090
C=O (amides)	1630–1680	O–H (acids)	2500–3500
C=O (aldehydes)	1660–1745	O–H (alcohols)	3200–3600
C=O (acids)	1680–1740	N–H (amines and amides)	3300–3500

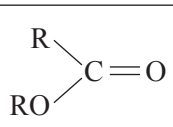
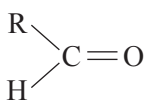
IN THE FINGERPRINT REGION AND DIFFICULT TO IDENTIFY

WAVENUMBER, FREQUENCY, ENERGY

WAVELENGTH

15. ^{13}C NMR data

Typical ^{13}C shift values relative to TMS = 0
These can differ slightly in different solvents.

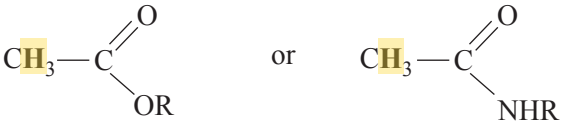
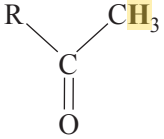
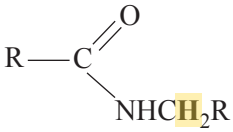
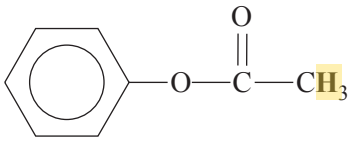
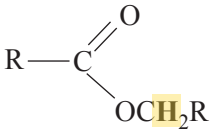
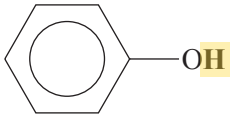
Type of carbon	Chemical shift (ppm)
$R–CH_3$	8–25
$R–CH_2–R$	20–45
$R_3–CH$	40–60
$R_4–C$	36–45
$R–CH_2–X$	15–80
$R_3C–NH_2$, $R_3C–NR$	35–70
$R–CH_2–OH$	50–90
$RC{\equiv}CR$	75–95
$R_2C{=}CR_2$	110–150
RCOOH	160–185
	165–175
	190–200
$R_2C{=}O$	205–220

THERE'S NO SPLITTING IN ^{13}C NMR

16. ^{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
	4.0–12.0

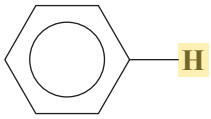
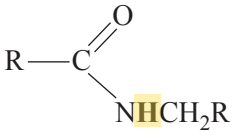
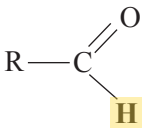
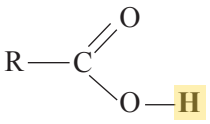
+1.0ppm if the H is close to a very polar group

$-CH_3$ $-CH_2-F$

always a singlet

always a singlet

singlet 1 doublet 2 triplet 3 quartet 4 ... ... multiplet n

Type of proton	Chemical shift (ppm)
	6.9–9.0
	8.1
	9.4–10.0
 always a singlet	9.0–13.0

ALWAYS SOLUBLE IN WATER

NO_3^- CH_3COO^- K^+ Na^+ NH_4^+

X^- EXCEPT FOR **S**ILVER, **M**ERCURY AND **L**EAD SALTS
(REMEMBER: S, M, L)

SO_4^{2-} EXCEPT FOR **B**ARIUM, **C**ALCIUM AND **L**EAD SALTS
(REMEBER: B, C, L)

NEVER SOLUBLE IN WATER

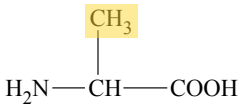
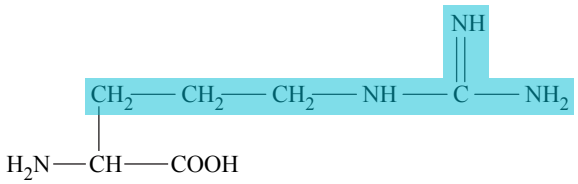
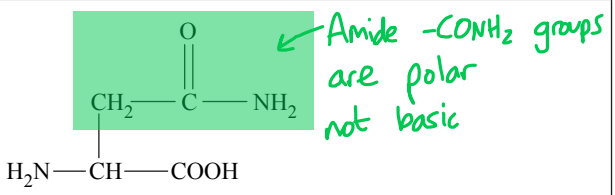
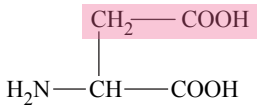
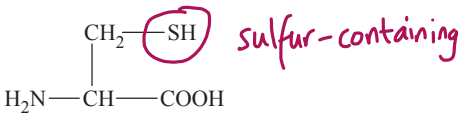
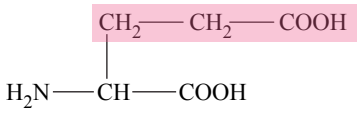
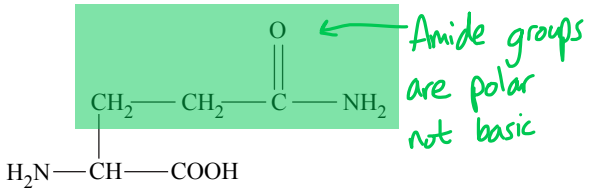
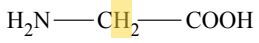
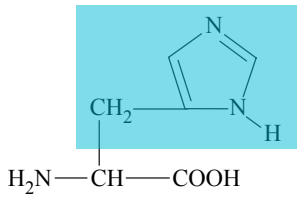
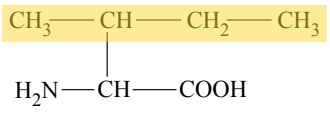
S^{2-} CO_3^{2-} PO_4^{3-} OH^-

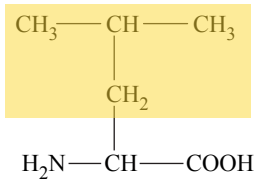
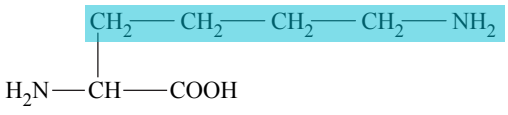
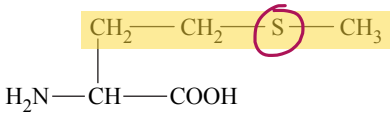
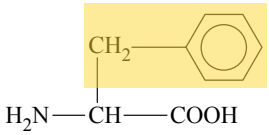
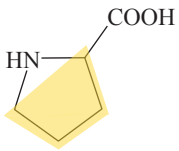
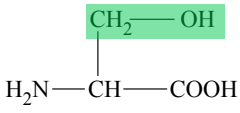
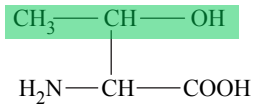
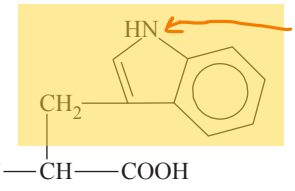
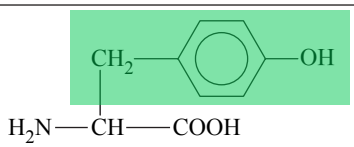
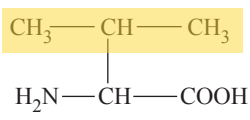
except for their group 1 or NH_4^+ compounds

ACIDIC SIDE-GROUP
NON-POLAR SIDE-GROUP
POLAR SIDE-GROUP
BASIC SIDE-GROUP

17. 2-amino acids (*α*-amino acids)

The table below provides simplified structures to enable the drawing of zwitterions, the identification of products of protein hydrolysis and the drawing of structures involving 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	
isoleucine	Ile	

Name	Symbol	Structure
leucine	Leu	
lysine	Lys	
methionine	Met	
phenylalanine	Phe	
proline	Pro	
serine	Ser	
threonine	Thr	
tryptophan	Trp	 Considered non-polar overall despite the –NH group
tyrosine	Tyr	
valine	Val	

END OF DATA BOOK