Neap

Trial Examination 2023

VCE Chemistry Unit 3

Written Examination

Suggested Solutions

SECTION A – MULTIPLE-CHOICE QUESTIONS

1	A	B	C	[✓ D]
2	[✓ A]	B	C	D
3	A	[✓ B]	C	D
4	A	B	C	[✓ D]
5	A	B	[✓ C]	D
6	A	B	C	[✓ D]
7	A	[✓ B]	C	D
8	A	[✓ B]	C	D
9	A	[✓ B]	C	D
10	A	B	[✓ C]	D

11	A	B	C	[✓ D]
12	[✓ A]	B	C	D
13	A	B	[✓ C]	D
14	A	B	C	[✓ D]
15	[✓ A]	B	C	D
16	A	B	C	[✓ D]
17	[✓ A]	B	C	D
18	A	B	[✓ C]	D
19	[✓ A]	B	C	D
20	A	B	[✓ C]	D

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Question 1 D

D is correct and **B** is incorrect. In a chemical reaction, a catalyst changes the rates of the forward and reverse reactions equally and lowers the activation energy, E_a; however, it has no effect on the enthalpy change, ΔH, of the reaction nor the enthalpies of the reactants and products.

A and **C** are incorrect. A catalyst lowers the E_a.

Question 2 A

A is correct. This option is the half-equation that correctly represents the oxidation process.

B is incorrect. The product of the incomplete combustion of methanol, CH_3OH, is water, H_2O, not hydrogen gas, H_2.

C is incorrect. This equation represents the reaction in the acid version of the fuel cell. Hydrogen ions, H^+, are not a reactant in the alkaline cell.

D is incorrect. The equation is not correctly balanced, and H_2O would be a liquid under standard laboratory conditions (SLC).

Question 3 B

B is correct. At 2 minutes, the temperature of the equilibrium mixture was changed. This means that the equilibrium constant, K_c, values at 1 minute and 5 minutes are not equal; that is, $K_{c1} \neq K_{c2}$. The change at 6 minutes, which is the removal of gas Q, does not change the K_c value; thus, $K_{c2} = K_{c3}$.

A, **C** and **D** are incorrect. The temperature change at 2 minutes caused the K_c value to change so that K_{c1} does not equal K_{c2} or K_{c3}.

Question 4 D

D is correct. At 3 minutes, the concentration of gas R was falling, and so the rate of formation must have been lower than the rate of decomposition.

A is incorrect. At 2 minutes, the temperature was changed and the position of equilibrium moved towards the reactants (P and Q). However, it is not certain whether the temperature was increased or decreased. If it was an increase, it was an exothermic reaction as the reverse reaction was favoured. If it was a decrease, the reaction must have been endothermic.

B is incorrect. At 6 minutes, some of gas Q was removed from the equilibrium mixture.

C is incorrect. Even though the concentrations did not change at equilibrium, the reaction was still occurring with the rate of formation equal to the rate of decomposition.

Question 5 C

A catalyst causes a reaction to reach equilibrium faster, but the concentrations of the components of a gaseous equilibrium do not change once equilibrium has been reached.

Question 6 D

D is correct. The reaction in a bioethanol fuel cell is exothermic, meaning that the products (carbon dioxide and water vapour) contain less energy than the reactants (ethanol and oxygen).

A is incorrect. The reaction of ethanol in a fuel cell is identical to the complete combustion of ethanol; therefore, it produces the greenhouse gases carbon dioxide and water vapour.

B is incorrect. Bioethanol molecules and molecules of ethanol derived from crude oil are identical in every respect.

C is incorrect. While the carbon dioxide used in photosynthesis by plants balances the carbon dioxide produced in a bioethanol fuel cell, the production of the bioethanol and construction of the fuel cell is likely to use some electricity produced by the burning of coal and other energy derived from the burning of fossil fuels. The production and use of bioethanol is therefore not likely to be 100% carbon neutral.

Question 7 B

Feature I applies to both galvanic and electrolytic cells. Energy transformations are not 100% efficient; some energy is lost as heat.

Feature II applies to galvanic cells only. Negative ions (anions) move towards the anode or positive electrode in electrolytic cells.

Feature III does not apply to galvanic cells nor electrolytic cells. Oxidising agents gain electrons; they do not lose them.

Feature IV applies to electrolytic cells only. The redox reactions in galvanic cells are spontaneous.

Therefore, **B** is correct.

Question 8 B

B is correct. The change at t_1 caused the rate of both the forward and reverse reactions to decrease. This is consistent with a decrease in temperature. The forward reaction was exothermic, as seen in the negative ΔH; therefore, a decrease in temperature would have meant that the forward reaction – the temperature-increasing reaction – was favoured. The rate of the forward reaction was higher than the rate of the reverse reaction until the new equilibrium was reached.

A is incorrect. Removing gas W would not have immediately affected the rate of the reverse reaction.

C is incorrect. Removing gas Z would not have immediately affected the rate of the forward reaction.

D is incorrect. Decreasing the volume would have increased the concentrations of all species and so would have increased the rates of both the forward and reverse reactions.

Question 9 B

B is correct. The products of the forward reaction become the reactants of the reverse reaction and require an E_a of 25 kJ mol^{-1} to overcome the activation barrier, as seen in the energy profile diagram.

A is incorrect. E_a is never negative.

C is incorrect. This value is the difference between the magnitude of the ΔH of the forward and reverse reactions (95 kJ mol^{-1}) and the E_a of the reverse reaction (25 kJ mol^{-1}); it has no relevance.

D is incorrect. This value is the magnitude of the ΔH of the forward and reverse reactions.

Question 10 C

C is correct. The cell reaction occurs according to the equation $Cl_2(g) + Sn^{2+}(aq) \rightarrow 2Cl^{-}(aq) + Sn^{4+}(aq)$. $Cl_2(g)$ gains electrons and so is reduced, meaning it is the oxidising agent. $Sn^{2+}(aq)$ causes the reduction and so is the reducing agent.

A is incorrect. $Cl_2(g)$ is the oxidising agent.

B is incorrect. $Cl^{-}(aq)$ is the conjugate reducing agent of the oxidising agent.

D is incorrect. $Sn^{4+}(aq)$ is the conjugate oxidising agent of the reducing agent.

Question 11 D

D is correct. The products of the spontaneous forward redox reaction become the reactants for the non-spontaneous redox reaction that occurs during electrolysis. For this to happen, the products of the spontaneous reaction must remain in contact with the electrodes.

A is incorrect. Electrolysis can occur in two separate half-cells as well as a single container.

B is incorrect. Electrolysis is often conducted using platinum, Pt, electrodes.

C is incorrect. If the products of a galvanic cell reaction do not remain in contact with the electrodes, no amount of energy will cause the spontaneous forward redox reaction to reverse.

Question 12 A

A is correct. The high concentration of chloride ions, Cl^{-}, means that predictions made using the electrochemical series are unreliable. Even though water, H_2O, is a stronger reducing agent than Cl^{-}, chlorine gas, Cl_2 – rather than oxygen gas, O_2 – is produced at the anode according to the equation $2Cl^{-}(aq) \rightarrow Cl_2(g) + 2e^{-}$. This is oxidation, which occurs at the anode (positive electrode) in an electrolytic cell. The information provided also indicates that the electrolytic cell produces Cl_2.

B is incorrect. Hydrogen gas, H_2, is produced at the cathode according to the following equation. $2H_2O(l) + 2e^{-} \rightarrow H_2(g) + 2OH^{-}(aq)$.

C is incorrect. O_2 is not produced at the anode because the high concentration of Cl^{-} makes the production of Cl_2 more likely.

D is incorrect. Sodium, Na, could only be produced at the cathode; however, as H_2O is a stronger oxidising agent than sodium ions, Na^{+}, Na is never produced from an aqueous solution.

Question 13 C

C is correct. Na^{+} is present in the brine and used to produce sodium hydroxide, NaOH, in the chamber containing the cathode (negative electrode). The polymer membrane prevents the passage of Cl^{-} into the cathode chamber; if Cl^{-} could pass to the cathode, it would mix with OH^{-}, resulting in an impure mix of NaOH and NaCl being collected.

A is incorrect. Cl_2 forms at the anode because of the high concentration of Cl^{-}, not because of the membrane.

B is incorrect. H_2 forms at the cathode because H_2O is a stronger oxidising agent than Na^{+}.

D is incorrect. Although used brine can be reclaimed from the cell, this is not the primary reason why the membrane is used.

Question 14 D

Reactant molecules must collide with sufficient energy and in the correct orientation in order for the bonds within them to be broken so that the products can form.

Question 15 A

$$n(\mathrm{e}^-) = \frac{It}{F} = \frac{0.25 \times 2.0 \times 60 \times 60}{96\ 500} = 0.0187\ \mathrm{C}$$

n(metal) = 0.0185 mol

As $n(\mathrm{e}^-) \approx n$(metal), the charge on each metal ion was +1.

Question 16 D

D is correct. The conclusions from the results are as follows.

- Metal L and J^{2+}(aq): J^{2+} ions are stronger oxidising agents than L^{2+} ions.
- Metal J and Q^{2+}(aq): Q^{2+} ions are stronger oxidising agents than J^{2+} ions.
- Metal Q and H^+(aq): Q^{2+} ions are stronger oxidising agents than H^+ ions.
- Metal L and H^+(aq): H^+ ions are stronger oxidising agents than L^{2+} ions.

Therefore, the order of decreasing oxidising strength is $Q^{2+} > J^{2+} > L^{2+}$, with H^+ ions being second or third in the order. The order of decreasing reducing strength is L > J > Q.

A is incorrect. Metal L is the strongest reducing agent.

B is incorrect. H^+ ions are weaker oxidising agents than Q^{2+} ions.

C is incorrect. Metal Q is a weaker reducing agent than metals J and L.

Question 17 A

A is correct. If mixing metal J with H^+ ions produces a reaction, then H^+ ions are stronger oxidising agents than J^{2+} ions. If no reaction occurs, then J^{2+} ions are stronger oxidising agents than H^+ ions. Either result makes it possible to place H^+ ions in the order of oxidising agents according to their relative oxidising strengths.

B is incorrect. The results have already established that J^{2+} ions are stronger oxidising agents than L^{2+} ions.

C is incorrect. The results have already established that Q^{2+} ions are stronger oxidising agents than J^{2+} ions.

D is incorrect. The results have already established that Q^{2+} ions are stronger oxidising agents than L^{2+} ions.

Question 18 C

C is correct. At the negatively charged anode, methane, CH_4, reacts with oxide ions, O^{2-}, to produce CO_2, H_2O and electrons. The electrons flow from the anode to the cathode, where they are used to reduce O_2 to O^{2-}. To complete the circuit, O^{2-} ions produced at the cathode travel though the electrolyte towards the anode, where they react with CH_4. The relevant equations are:

- $CH_4 + 4O^{2-} \rightarrow CO_2 + 2H_2O + 8e^-$
- $O_2 + 4e^- \rightarrow 2O^{2-}$

A is incorrect. The oxidation number of carbon changes from –4 in CH_4 to +4 in CO_2.

B is incorrect. O_2 is reduced at the positively charged cathode.

D is incorrect. Electrons flow from the anode to the cathode.

Question 19 A

A is correct. A secondary cell produces electrical energy by separating two spontaneous half-reactions into separate containers and making the transfer of electrons proceed along a connecting wire. If one or more of the reactants is depleted, the cell reaction will stop and no electricity will be produced; that is, the battery is ‘flat’.

B is incorrect. A secondary cell is rechargeable and so the products of the cell reaction must be kept in contact with the electrodes so that the cell reaction can be reversed by inputting electrical energy. If a product escapes from the cell, then recharging would not be possible; however, this does not best explain why a battery becomes flat.

C is incorrect. In a secondary cell, electrons move through a connecting wire; they do not flow through the electrolyte.

D is incorrect. In a secondary cell, the electrodes must be intact for the cell reaction to be reversed so that the cell can be recharged. If an electrode is consumed, then recharging would not be possible; however, this does not best explain why a battery becomes flat.

Question 20 C

Electrons are forced back onto the negative electrode of the cell when recharging using electrical energy from the power source. This causes the reactants to gain electrons, which is reduction.

SECTION B

Question 1 (13 marks)

a. **i.** $C_3H_8(g) + 5O_2(g) \rightarrow 3CO_2(g) + 4H_2O(l) \qquad \Delta H = -2220 \text{ kJ mol}^{-1}$

2 marks

1 mark for providing the correct balanced equation.

1 mark for providing the enthalpy change, including the negative sign.

ii. At SLC, 1.0 L of C_3H_8 contains $\frac{1.0}{24.8}$ mol of gas. 1 mark

$n(CO_2) = 3 \times n(C_3H_8) = 3 \times \frac{1.0}{24.8} = 0.1210 \text{ mol}$ 1 mark

$m(CO_2) = n \times M = 0.1210 \times 44.0 = 5.32258 = 5.32 \text{ g}$ 1 mark

iii. energy released by burning C_3H_8 = 2220 × 0.461 = 1023 kJ 1 mark

only 65% of the heat energy was transferred, therefore:

$$\begin{aligned} 65\% \text{ of the energy transferred} &= 1023 \times 0.650 \\ &= 665.0 \text{ kJ} \end{aligned}$$

1 mark

$$\Delta T = \frac{E}{m \times c} = \frac{665.0 \times 10^3}{15\,000 \times 4.18} = 10.61°C$$

$\Delta T = T_{final} - T_{initial}$; hence, $T_{final} = 17.8 + 10.61 = 28.4°C$. 1 mark

b. **i.** To write a thermochemical equation, the energy released in the combustion of a known amount of a single compound must be known. As kerosene is a mixture of compounds, it is not possible to satisfy this requirement. 1 mark

ii. As the molecules in kerosene are smaller than those in petrodiesel, the dispersion forces between the molecules in kerosene are likely to be less intense than those in petrodiesel. 1 mark

At a set temperature, the molecules in kerosene would therefore move more freely than those in petrodiesel, and so kerosene is likely to have a lower viscosity. 1 mark

iii. $m(\text{kerosene that would produce 10.5 MJ of energy}) = \frac{10.5 \times 10^3}{43.7}$ 1 mark

$= 240.27 = 240 \text{ g}$ 1 mark

Question 2 (12 marks)

a. **i.**

	SO_2	**Cl_2**	**SO_2Cl_2**
***n*(initial)**	2.0	1.0	0.0
Change	–0.70	–0.70	+0.70
***n*(equilibrium)**	1.3	0.30	0.70
$c(\text{equilibrium}) = \dfrac{n(\text{equilibrium})}{2.0}$	0.65 M	0.15 M	0.35 M

3 marks

1 mark for each gas concentration.

ii. reaction quotient (or concentration fraction), $Q = \dfrac{[SO_2Cl_2]}{[SO_2][Cl_2]}$ 1 mark

$$= \frac{0.35}{0.65 \times 0.15} = 3.59 = 3.6\ M^{-1}$$ 1 mark

The K_c at T_1 is 3.8 M^{-1} and so the system did not reach equilibrium because the value of the reaction quotient does not equal the value of the K_c. 1 mark

Note: Consequential on answer to ***Question 2a.i.***

b. At T_2, the value of the K_c is higher, meaning that $[SO_2Cl_2]$ has increased, and $[SO_2]$ and $[Cl_2]$ have decreased. 1 mark

The formation of SO_2Cl_2 (forward reaction) is exothermic, and so the system must have been cooled for the formation of products to be favoured; therefore, T_2 is lower than T_1. 1 mark

c.

Change made to the equilibrium mixture	**Position of equilibrium**			**Explanation**
	Moved towards products	**Moved towards reactants**	**Did not move**	
Volume was decreased at constant temperature.	✓			**The pressure would have increased, and so the side of the reaction with fewer moles of gas (that is, the forward reaction) would have been favoured according to Le Chatelier's principle.**
Pressure was increased by the addition of argon gas at constant volume.			✓	**The addition of argon would not have changed the concentrations of the gases in the system, and so the position of equilibrium would not have moved.**

4 marks

1 mark for each change in position of equilibrium identified.

1 mark for each explanation provided.

Question 3 (11 marks)

a. **i.** voltage = E^0 (oxidising agent) – E^0 (reducing agent) = 0.77 – (–0.50) = 1.27 V 1 mark

ii. $Fe^{3+}(aq) + e^- \rightarrow Fe^{2+}(aq)$ 1 mark

iii. The salt bridge provides electrical connection between the half-cells by allowing the free movement of ions in both directions. The movement of the ions keeps the overall charge of the half-cells neutral. 1 mark

iv.

Statement	Correct or incorrect	Explanation for why the statement is correct or incorrect
As ethanol (C_2H_5OH) is completely soluble in water, it can be used to wet the salt bridge to enable the galvanic cell to operate.	**incorrect**	**The liquid used to wet the salt bridge must contain ions so that ion movement can occur between the half-cells; as ethanol does not contain ions, it is not suitable.**
A chromium electrode must be used in the $Cr^{3+}(aq)/Cr^{2+}(aq)$ half-cell and an iron electrode must be used in the $Fe^{3+}(aq)/Fe^{2+}(aq)$ half-cell.	**incorrect**	**Using chromium and iron electrodes would introduce metals into the galvanic cell that are capable of reacting with the components of the cell, and so the overall cell reaction and voltage would be uncertain.**

3 marks

1 mark for stating that both statements are incorrect.
1 mark for each explanation provided.

b. **i.** the ability to allow ions to pass through 1 mark

ii. $Fe^{3+}(aq) + e^- \rightarrow Fe^{2+}(aq)$ 1 mark

iii. $Cr^{3+}(aq) + e^- \rightarrow Cr^{2+}(aq)$ 1 mark

iv. The electrodes are not porous because the reactants are not gases, which would need to pass through the electrodes so that contact between the gas and electrolyte is made. 1 mark

The electrodes could be catalytic so that a fast reaction is ensured if the uncatalysed reaction is too slow for this application. 1 mark

Question 4 (6 marks)

a. In 1.0 m^3 of the biogas, there is $\frac{0.5\times1000}{100}=5\text{ L}$ of H_2, which at SLC is $\frac{5}{24.8}\text{ mol}$ of H_2. 1 mark

$m(H_2)=n\times M=\frac{5}{24.8}\times2.0=0.4032\text{ g}=0.4\text{ g}$ 1 mark

b. The organic waste matter source material used to produce biogas is renewable as it can be grown repeatedly in a relatively short time. The H_2 in biogas is therefore renewable. 1 mark

The CH_4 from biogas can be converted to H_2 using the steam-reforming process. Therefore, this H_2 is also renewable. 1 mark

c. Burning H_2 requires a number of energy conversions to produce movement in a car and some energy is lost at each conversion with significant overall heat loss. 1 mark

Using H_2 in a fuel cell requires only one energy conversion of chemical energy to electrical energy. With less conversions there is less energy lost and so this method is more energy efficient. 1 mark

Question 5 (7 marks)

a. Water is a stronger oxidising agent than magnesium ions. 1 mark

Thus, if an aqueous solution were used, water would react at the cathode preferentially and no magnesium metal would form. 1 mark

b. Iron is a relatively inexpensive metal and can be used as the cathode as no reaction will occur between magnesium ions and iron. 1 mark

Iron is a stronger reducing agent than chloride ions, and so it would react if it were used as the anode. 1 mark

c. $2Cl^-(l) \rightarrow Cl_2(g) + 2e^-$ 1 mark

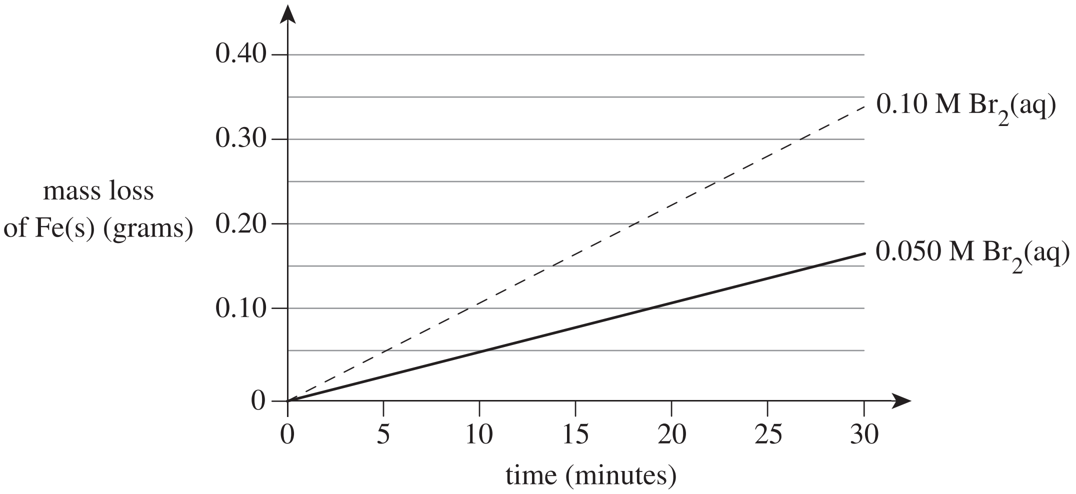
d. ceramic hood 1 mark

The products of the electrolysis (Mg and Cl_2) are the reactants of a spontaneous redox reaction. If these products were mixed, the spontaneous reaction would occur, and so no Mg or Cl_2 would be obtained. The ceramic hood prevents this mixing. 1 mark

Question 6 (6 marks)

a. average rate of reaction $= \frac{\Delta m}{\Delta t} = \frac{0.34}{30} = 0.011$ g of Fe min^{-1} 1 mark

b. **i.**



1 mark

ii. The 0.050 M Br_2 solution has half the concentration of the original 0.10 M Br_2 solution and so half the number of moles of particles in a set volume. 1 mark

The number of collisions between the reactants would therefore be approximately halved and the number of successful collisions would also be halved. Therefore, the rate of reaction would be approximately half the rate of the original 0.10 M Br_2 solution experiment. 1 mark

c. Based on the electrochemical series, the stronger oxidising agent, Br_2, reacts spontaneously with the stronger reducing agent, Fe. 1 mark

This spontaneous redox reaction would be exothermic. 1 mark

Neap

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Written Examination

Data Booklet

Instructions

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

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

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1. Periodic table of the elements

atomic number — 79 — symbol of element — **Au**
relative atomic mass — 197.0
name of element — gold

1 **H** 1.0 hydrogen																	2 **He** 4.00 helium
3 **Li** 6.9 lithium	4 **Be** 9.0 beryllium											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
11 **Na** 23.0 sodium	12 **Mg** 24.3 magnesium											13 **Al** 27.0 aluminium	14 **Si** 28.1 silicon	15 **P** 30.1 phosphorus	16 **S** 32.1 sulfur	17 **Cl** 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** 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** 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

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 homium	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

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

2. 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
$Au^+(aq) + e^- \rightleftharpoons Au(s)$	+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

3. Chemical relationships

Name	Formula
number of moles of a substance	$n = \frac{m}{M}$; $n = cV$; $n = \frac{V}{V_\text{m}}$
universal gas equation	$pV = nRT$
calibration factor (CF) for bomb calorimetry	$\text{CF} = \frac{VIt}{\Delta T}$
heat energy released in the combustion of a fuel	$q = mc\Delta T$
enthalpy of combustion	$\Delta H = \frac{q}{n}$
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}

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

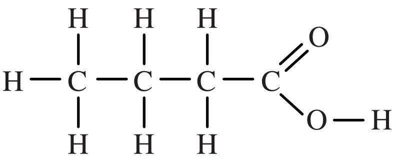
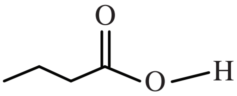
Metric (including SI) prefixes	Scientific notation	Multiplying factor
giga (G)	10^9	1 000 000 000
mega (M)	10^6	1 000 000
kilo (k)	10^3	1000
deci (d)	10^{-1}	0.1
centi (c)	10^{-2}	0.01
milli (m)	10^{-3}	0.001
micro (μ)	10^{-6}	0.000001
nano (n)	10^{-9}	0.000000001
pico (p)	10^{-12}	0.000000000001

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

8. Representations of organic molecules

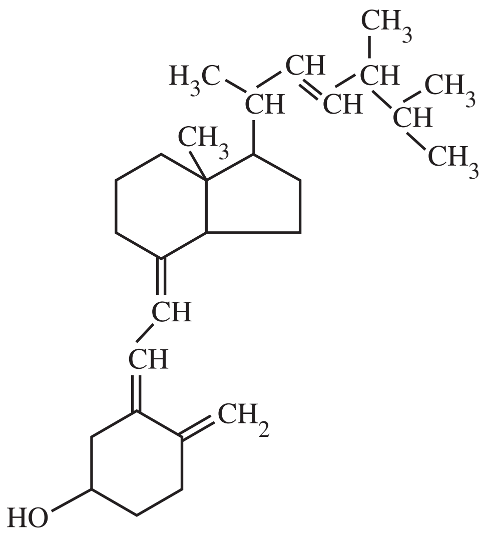
The following table shows different representations of organic molecules, using butanoic acid as an example.

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

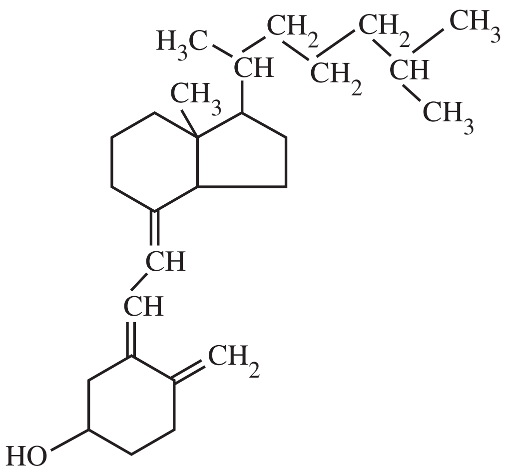
9. Formulas of some fatty acids

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

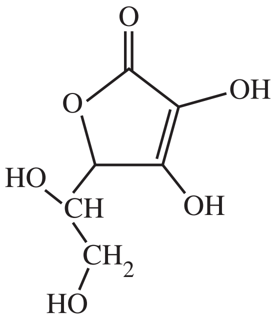
10. Formulas of some biomolecules



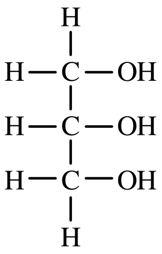
vitamin D_2 (ergocalciferol)



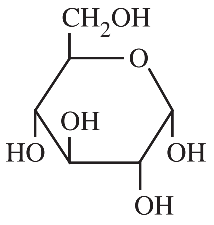
vitamin D_3 (cholecalciferol)



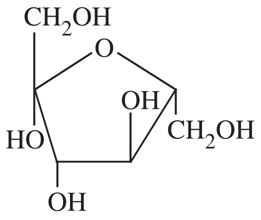
vitamin C (ascorbic acid)



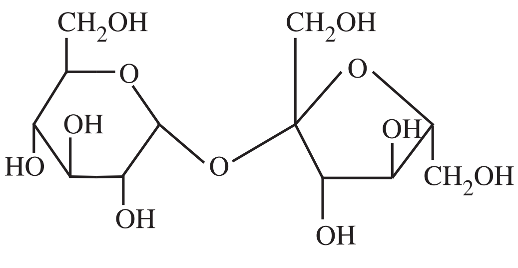
glycerol



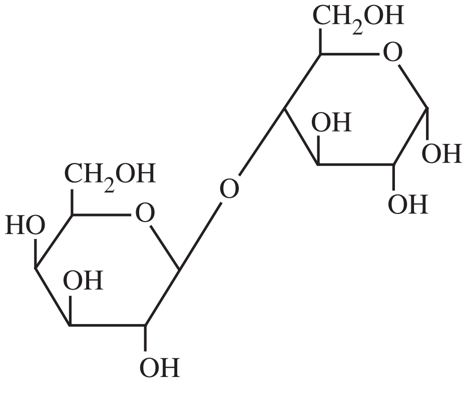
α-glucose



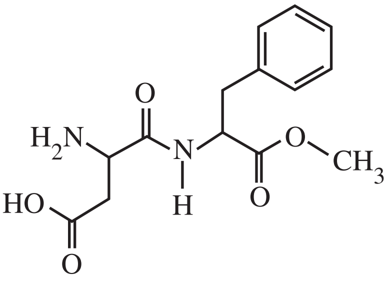
β-fructose

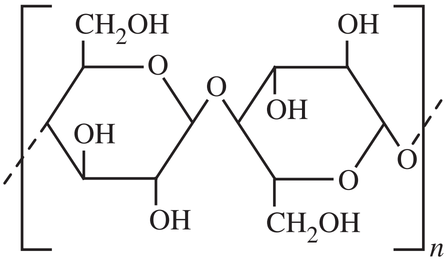


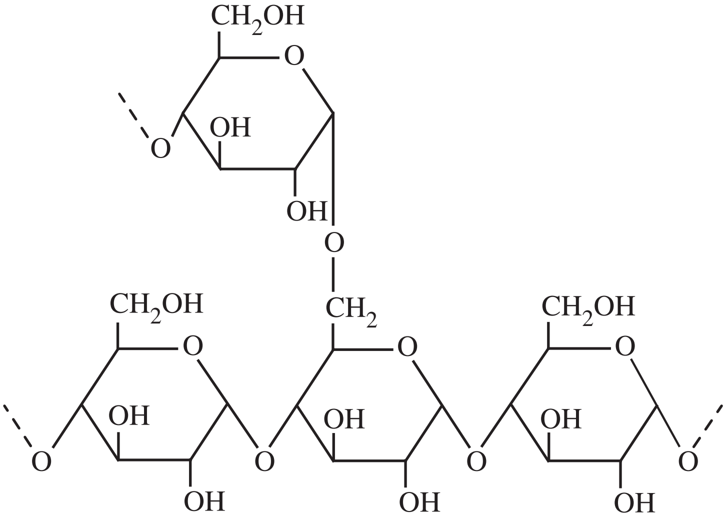
sucrose

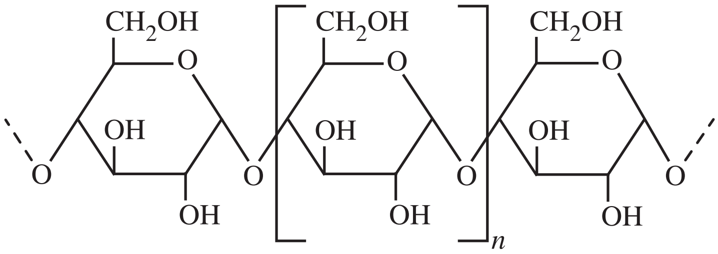


α-lactose


aspartame


cellulose


amylopectin (starch)


amylose (starch)

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.

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

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

13. Energy content of food groups

Food	**Heat of combustion ($kJ\ g^{-1}$)**
fats and oils	37
protein	17
carbohydrate	16

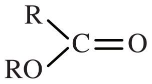
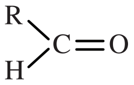
14. Characteristic ranges for infra-red absorption

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

15. ^{13}C NMR data

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

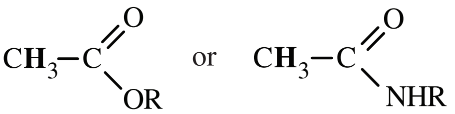
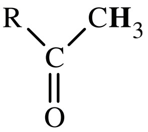
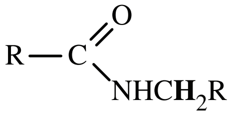
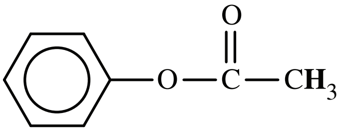
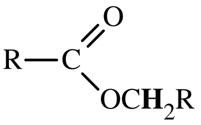
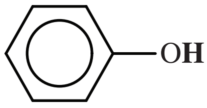
These can differ slightly in different solvents.

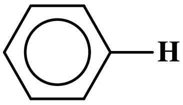
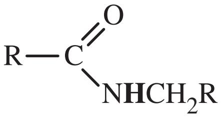
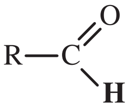
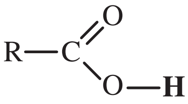
Type of carbon	Chemical shift (ppm)
$R–CH_3$	8–25
$R–CH_2–R$	20–45
$R_3–CH$	40–60
$R_4–C$	36–45
$R–CH_2–X$	15–80
$R_3C–NH_2$, $R_3C–NR$	35–70
$R–CH_2–OH$	50–90
$RC≡CR$	75–95
$R_2C=CR_2$	110–150
RCOOH	160–185
	165–175
	190–200
$R_2C=O$	205–220

16. ^{1}H NMR data

Typical proton shift values relative to TMS = 0

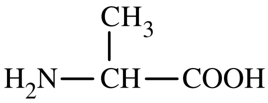
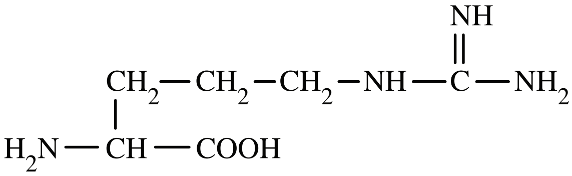
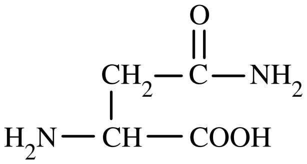
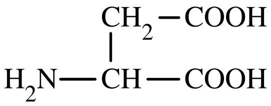
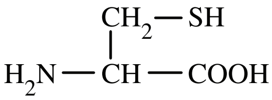
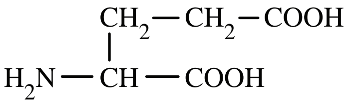
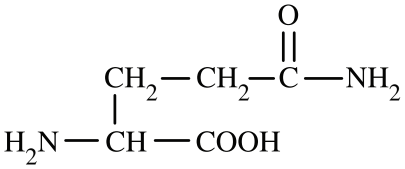
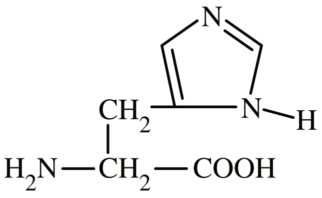
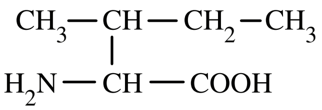
These can differ slightly in different solvents. The shift refers to the proton environment that is indicated in bold letters in the formula.

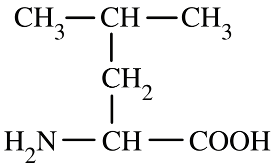
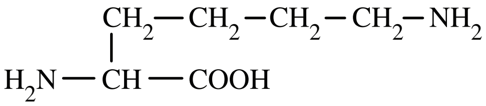
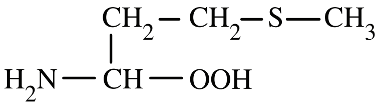
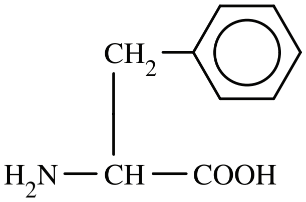
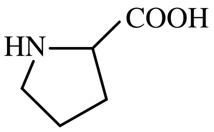
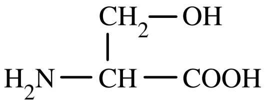
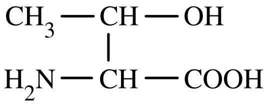
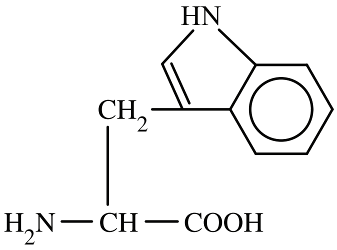
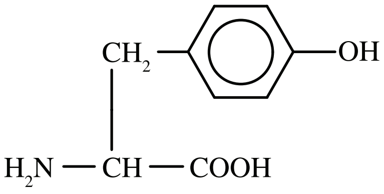
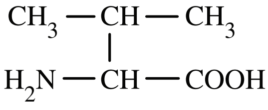
Type of proton	Chemical shift (ppm)
$R–C\mathbf{H}_3$	0.9–1.0
$R–C\mathbf{H}_2–R$	1.3–1.4
$RCH{=}CH–C\mathbf{H}_3$	1.6–1.9
$R_3–C\mathbf{H}$	1.5
	2.0
	2.1–2.7
$R–C\mathbf{H}_2–X$ (X = F, Cl, Br or I)	3.0–4.5
$R–C\mathbf{H}_2–OH$, $R_2–C\mathbf{H}–OH$	3.3–4.5
	3.2
$R–O–C\mathbf{H}_3$ or $R–O–C\mathbf{H}_2R$	3.3–3.7
	2.3
	3.7–4.8
$R–O–\mathbf{H}$	1– 6 (varies considerably under different conditions)
$R–N\mathbf{H}_2$	1–5
$RHC{=}C\mathbf{H}R$	4.5–7.0
	4.0–12.0

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

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	 $H_2N-CH(CH_3)-COOH$
arginine	Arg	 $H_2N-CH(CH_2-CH_2-CH_2-NH-C(=NH)-NH_2)-COOH$
asparagine	Asn	 $H_2N-CH(CH_2-C(=O)-NH_2)-COOH$
aspartic acid	Asp	 $H_2N-CH(CH_2-COOH)-COOH$
cysteine	Cys	 $H_2N-CH(CH_2-SH)-COOH$
glutamic acid	Glu	 $H_2N-CH(CH_2-CH_2-COOH)-COOH$
glutamine	Gln	 $H_2N-CH(CH_2-CH_2-C(=O)-NH_2)-COOH$
glycine	Gly	H_2N-CH_2-COOH
histidine	His	
isoleucine	Ile	 $H_2N-CH(CH(CH_3)-CH_2-CH_3)-COOH$

Name	Symbol	Structure
leucine	Leu	 $\begin{array}{l} CH_3-CH-CH_3 \\ \qquad \vert \\ \qquad CH_2 \\ \qquad \vert \\ H_2N-CH-COOH \end{array}$
lysine	Lys	 $\begin{array}{l} \qquad CH_2-CH_2-CH_2-CH_2-NH_2 \\ \qquad \vert \\ H_2N-CH-COOH \end{array}$
methionine	Met	 $\begin{array}{l} \qquad CH_2-CH_2-S-CH_3 \\ \qquad \vert \\ H_2N-CH-OOH \end{array}$
phenylalanine	Phe	
proline	Pro	
serine	Ser	 $\begin{array}{l} \qquad CH_2-OH \\ \qquad \vert \\ H_2N-CH-COOH \end{array}$
threonine	Thr	 $\begin{array}{l} CH_3-CH-OH \\ \qquad \vert \\ H_2N-CH-COOH \end{array}$
tryptophan	Trp	
tyrosine	Tyr	
valine	Val	 $\begin{array}{l} CH_3-CH-CH_3 \\ \qquad \vert \\ H_2N-CH-COOH \end{array}$

END OF DATA BOOKLET