Oxford Resources for IB

Chemistry – 2023 Edition

Answers

Structure 3.1 – The periodic table: Classification of elements

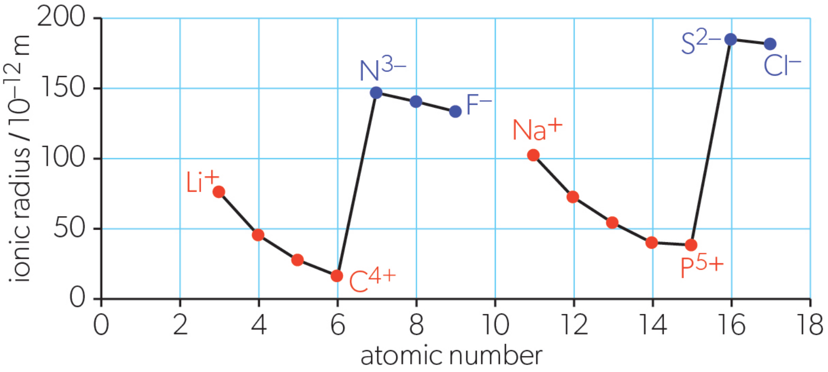
Practice questions (page 231)

1. **a.** **i.** oxygen, O
   - **ii.** chalcogens
   - **iii.** 2
   - **iv.** $1s^2\,2s^2\,2p^4$
   - **v.** $[He]\,2s^2\,2p^4$

   b. **i.** magnesium, Mg
   - **ii.** alkaline earth metals
   - **iii.** 3
   - **iv.** $1s^2\,2s^2\,2p^6\,3s^2$
   - **v.** $[Ne]\,3s^2$

   c. **i.** iron, Fe
   - **ii.** transition elements
   - **iii.** 4
   - **iv.** $1s^2\,2s^2\,2p^6\,3s^2\,3p^6\,3d^6\,4s^2$
   - **v.** $[Ar]\,3d^6\,4s^2$

Data-based question (page 234)



As the atomic number and hence the number of protons in the nucleus increase, the outermost electrons are held closer to the nucleus by the increasing nuclear charge. At the same time, the shielding effect remains nearly constant because the number of inner electrons does not change. Therefore, ionic radii of both cations and anions decrease across the period (from left to right).

The discontinuities in this trend are caused by the fact that for early elements in each period (Li to C and Na to P), the ionic radii in the data booklet are given for cations while for later elements (N to F, S and Cl), they are given for anions. Anions have more electrons than protons, so their ionic radii are higher because of the increased mutual repulsion between electrons.

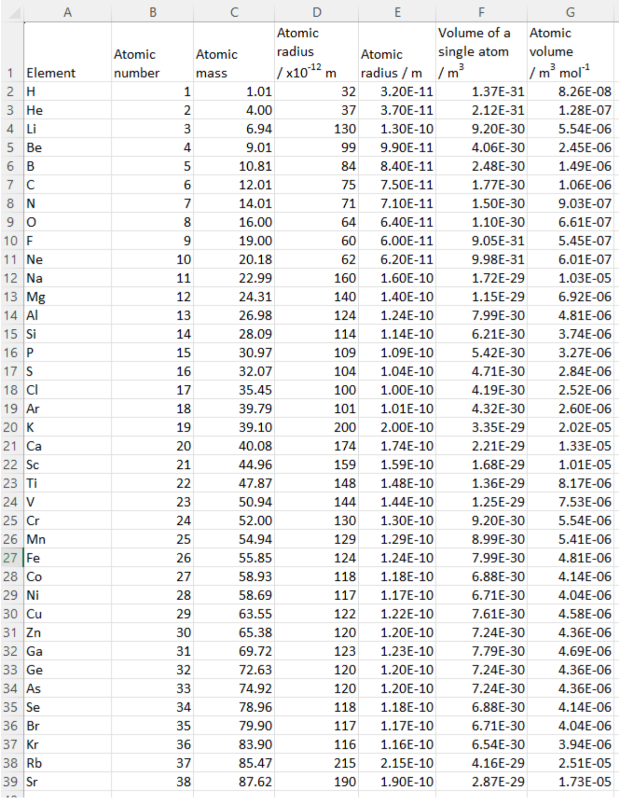
Noble gases (Ne and Ar) do not form stable cations, so their ionic radii are not given in the data booklet.

Activity (page 237)

Property	Sr or I	Mg or Ca	C or Si	Li or F	Ba or Cl	K or Br	C or Pb	Cs or F
atomic radius	Sr	Ca	Si	Li	Ba	K	Pb	Cs
ionic radius	I	Ca	Si	F	Cl	Br	Pb	Cs
electron affinity	I	Ca	C	F	Cl	Br	C	F
ionization energy	I	Mg	C	F	Cl	Br	C	F
electronegativity	I	Mg	C	F	Cl	Br	C	F

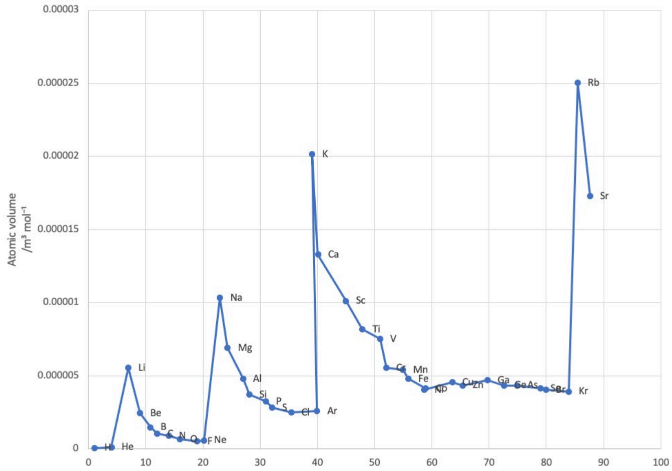
Skills question (page 237)

1 to 5. Example data:



	A	B	C	D	E	F	G
1	Element	Atomic number	Atomic mass	Atomic radius / x10^{-12} m	Atomic radius / m	Volume of a single atom / m^3	Atomic volume / m^3 mol^{-1}
2	H	1	1.01	32	3.20E-11	1.37E-31	8.26E-08
3	He	2	4.00	37	3.70E-11	2.12E-31	1.28E-07
4	Li	3	6.94	130	1.30E-10	9.20E-30	5.54E-06
5	Be	4	9.01	99	9.90E-11	4.06E-30	2.45E-06
6	B	5	10.81	84	8.40E-11	2.48E-30	1.49E-06
7	C	6	12.01	75	7.50E-11	1.77E-30	1.06E-06
8	N	7	14.01	71	7.10E-11	1.50E-30	9.03E-07
9	O	8	16.00	64	6.40E-11	1.10E-30	6.61E-07
10	F	9	19.00	60	6.00E-11	9.05E-31	5.45E-07
11	Ne	10	20.18	62	6.20E-11	9.98E-31	6.01E-07
12	Na	11	22.99	160	1.60E-10	1.72E-29	1.03E-05
13	Mg	12	24.31	140	1.40E-10	1.15E-29	6.92E-06
14	Al	13	26.98	124	1.24E-10	7.99E-30	4.81E-06
15	Si	14	28.09	114	1.14E-10	6.21E-30	3.74E-06
16	P	15	30.97	109	1.09E-10	5.42E-30	3.27E-06
17	S	16	32.07	104	1.04E-10	4.71E-30	2.84E-06
18	Cl	17	35.45	100	1.00E-10	4.19E-30	2.52E-06
19	Ar	18	39.79	101	1.01E-10	4.32E-30	2.60E-06
20	K	19	39.10	200	2.00E-10	3.35E-29	2.02E-05
21	Ca	20	40.08	174	1.74E-10	2.21E-29	1.33E-05
22	Sc	21	44.96	159	1.59E-10	1.68E-29	1.01E-05
23	Ti	22	47.87	148	1.48E-10	1.36E-29	8.17E-06
24	V	23	50.94	144	1.44E-10	1.25E-29	7.53E-06
25	Cr	24	52.00	130	1.30E-10	9.20E-30	5.54E-06
26	Mn	25	54.94	129	1.29E-10	8.99E-30	5.41E-06
27	Fe	26	55.85	124	1.24E-10	7.99E-30	4.81E-06
28	Co	27	58.93	118	1.18E-10	6.88E-30	4.14E-06
29	Ni	28	58.69	117	1.17E-10	6.71E-30	4.04E-06
30	Cu	29	63.55	122	1.22E-10	7.61E-30	4.58E-06
31	Zn	30	65.38	120	1.20E-10	7.24E-30	4.36E-06
32	Ga	31	69.72	123	1.23E-10	7.79E-30	4.69E-06
33	Ge	32	72.63	120	1.20E-10	7.24E-30	4.36E-06
34	As	33	74.92	120	1.20E-10	7.24E-30	4.36E-06
35	Se	34	78.96	118	1.18E-10	6.88E-30	4.14E-06
36	Br	35	79.90	117	1.17E-10	6.71E-30	4.04E-06
37	Kr	36	83.90	116	1.16E-10	6.54E-30	3.94E-06
38	Rb	37	85.47	215	2.15E-10	4.16E-29	2.51E-05
39	Sr	38	87.62	190	1.90E-10	2.87E-29	1.73E-05

Example graph:



6. Answers will vary. Guidance: the idea of a repeating pattern across periods should be mentioned, with the group 1 elements having a large atomic volume, which decreases across the period.

7. Answers will vary. Guidance: you should notice that the law of octaves is only apparent until argon.

8. Answers will vary e.g. V, vanadium

Activity (page 239)

	F^-	Cl^-	Br^-	I^-
F_2	No reaction	$F_2 + 2Cl^- \rightarrow 2F^- + Cl_2$	$F_2 + 2Br^- \rightarrow 2F^- + Br_2$	$F_2 + 2I^- \rightarrow 2F^- + I_2$
Cl_2	No reaction	No reaction	$Cl_2 + 2Br^- \rightarrow 2Cl^- + Br_2$	$Cl_2 + 2I^- \rightarrow 2Cl^- + I_2$
Br_2	No reaction	No reaction	No reaction	$Br_2 + 2I^- \rightarrow 2Br^- + I_2$
I_2	No reaction	No reaction	No reaction	No reaction

Practice questions (page 240)

1. potassium + water → potassium hydroxide + hydrogen

   $2K(s) + 2H_2O(l) \rightarrow 2KOH(aq) + H_2(g)$
2. Fr, Cs, Rb, K, Na, Li
3. **a.** $Li + F_2$
   b. $Ba + Cl_2$
   c. $K + Cl_2$
   d. $F_2 + KI$

Approaches to learning question (page 240)

Answers will vary widely depending on the periodic tables selected.

Practice questions (page 244)

4. **a.** K: +1, Cr: +6, O: –2
   b. C: –4, H: +1
   c. C: +4, O: –2
   d. H: +1, Cl: +7, O: –2
   e. O: +2, F: –1
   f. S: +4, O: –2
   g. Na: +1, H: –1
   h. Fe: +3, O: –2
   j. C: –2, H: +1, O: –2
   k. C: 0, H: +1, O: –2
   l. Na: +1, O: –1

Practice questions (page 245)

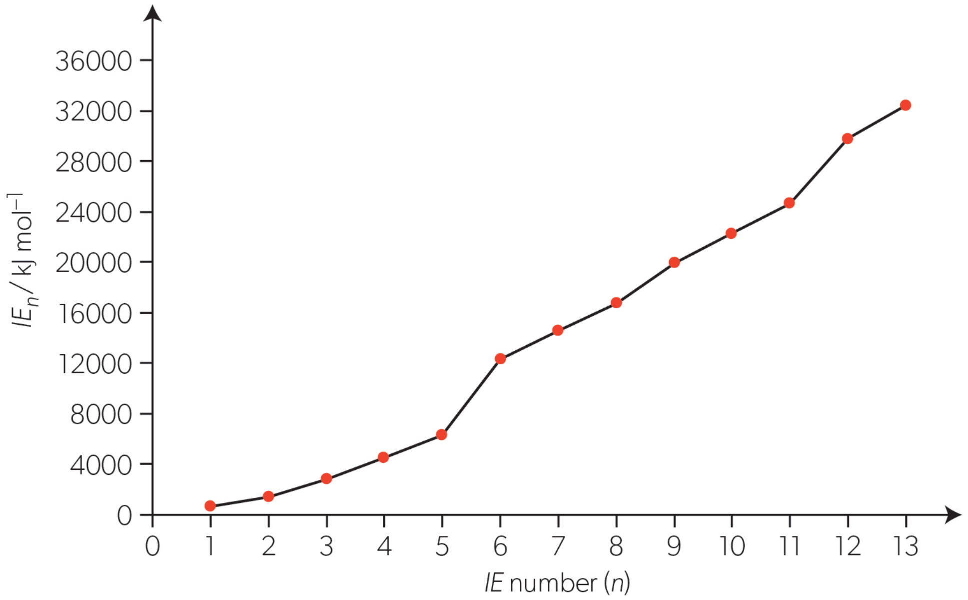
5. **a.** HNO_3
   b. Na_3PO_4
   c. $Mg(BrO_2)_2$
   d. K_2SO_3

Approaches to learning question (page 245)

1. L should be lower case: HCl
2. E should be lower case: He
3. 3 should be subscript: O_3
4. OH should be in parentheses, 2 should be subscript: $Mg(OH)_2$
5. Should use English, not Latin**:** copper(II) oxide

Activity (page 250)

As an example, the plot for the third transition element of period 4, vanadium, is given below.



The first five ionization energies of vanadium are relatively low, and they increase very gradually, so vanadium shows a variety of oxidation states, from +1 to +5, in its compounds. The oxidation state +5 corresponds to the most stable valence electron configuration, [Ar], so vanadium(V) compounds are the most common. The sharp rise in ionization energy from IE_5 to IE_6 makes the removal of the sixth electron very unfavourable, so the compounds of vanadium in oxidation states greater than +5 are unknown.

The stability of certain oxidation states for other transition elements can be explained in a similar manner. The successive IE plots and oxidation states of chromium and copper are discussed in the main text.

Practice questions (page 250)

6. Mn^{2+} is formed from Mn by losing the two 4s valence electrons, leaving the ion with a particularly stable half-filled 3d sublevel, [Ar] $3d^5$. To become Mn^{3+}, this ion will have to break this stable configuration by losing one of the 3d electrons. This is unfavourable, so Mn^{3+} is less stable than Mn^{2+}.

Fe^{2+} is formed from Fe by losing the two 4s valence electrons, leaving the ion [Ar] $3d^6$. The paired electrons in one 3d orbital experience extra repulsion, so one of these electrons is easily removed to form the Fe^{3+} ion with a more stable [Ar] $3d^5$ configuration.

7. a. [Ar] $4s^2$ $3d^3$

b. In oxidation state +5, vanadium formally loses all its valence electrons and gains a particularly stable configuration of a noble gas, [Ar].

Practice question (page 253)

8. The chloride ions can replace water molecules in the complex, for example:

$[Cu(H_2O)_6]^{2+}(aq) + Cl^-(aq) \rightleftharpoons [Cu(H_2O)_5Cl]^+(aq) + H_2O(l)$

Chloride ions will produce less splitting between the two non-degenerate d-orbitals of Cu than did water. This means that light of lower energy, lower frequency, and longer wavelength will be absorbed when electrons are promoted between the two non-degenerate d-orbitals. The complementary colour transmitted by the copper(II)–chloride complex will be different than that of the copper(II)–water complex.

Skills question (page 253)

Answers will vary depending on the data collected. The guidance on graphs and uncertainties in Tool 3 should be followed.

End of topic questions (pages 254–255)

1. Answers will depend on the student, but a possible answer might be: The elements in a particular period have outer electrons in the same energy level while the elements in a particular group have a common number of valence electrons. The chemical properties of the elements depend on their electron configuration, so they change gradually in both periods and groups. Across a period, metallic character of the elements decreases while non-metallic character increases. As a result, the chemical properties of oxides change from basic (for most active metals) through amphoteric (for less active metals and metalloids) to acidic (for non-metals). Down a group, metallic character of the elements increases while non-metallic character decreases. Transition elements with incomplete d-sublevels have variable oxidation states that also demonstrate clear periodic trends.

2. C

3. A

4. A

5. D

6. D

7. A

8. C

9. C

10. C

11. A

12. C

13. C

14. C

15. a. Descending the group, atoms have a greater number of shells/energy levels;

For example, lithium has 2, sodium has 3 and potassium has 4.

b. Fluorine has greater effective nuclear charge / more protons than oxygen

OR

Fluorine has 9 protons and oxygen has 8; Fluorine has a smaller radius than oxygen

OR

Fluorine and oxygen have the same number of shells/energy levels;

c. Cl has 17 electrons AND Cl^- has 18

OR

Cl^- has one more electron than Cl

OR

Cl: $1s^2\,2s^2\,2p^6\,3s^2\,3p^5$ AND Cl^-: $1s^2\,2s^2\,2p^6\,3s^2\,3p^6$; Cl^- has more electron-electron repulsion hence larger radius;

d. i. $Cl_2(g) + 2KBr(aq) \rightarrow 2KCl(aq) + Br_2(l)$

M1: correct reactants, products and balancing; M2: correct state symbols

Accept $Br_2(aq)$ instead of $Br_2(l)$

ii. Chlorine is more reactive than bromine;

So chlorine displaces bromine from its compound

OR

Chlorine is a stronger oxidizing agent than bromine; So it is reduced, and bromine, oxidised;

Accept converse explanations for bromine being less reactive/weaker oxidising agent.

16. a. One/1

b. Down group the atoms have more shells/energy levels / atomic radius increases;

Less energy needed to overcome decreased attraction between nucleus and outer electrons;

c. i. Colourless to pink

Do not accept "clear".

ii. Any value between 9 and 14

d. $2Rb(s) + 2H_2O(l) \rightarrow 2RbOH(aq) + H_2(g)$

M1: correct reactants, products and balancing;

M2: correct state symbols

17. a. Rainwater is naturally acidic due to the presence of dissolved carbon dioxide, forming weak carbonic acid;

$CO_2(g) + H_2O(l) \rightarrow H_2CO_3(aq)$;

b. Combustion causes the (small amounts) of sulfur in coal to form sulfur dioxide;

Sulfur dioxide dissolves in water to produce sulfurous acid, which is then oxidized by atmospheric oxygen into sulfuric acid;

c. i. metal corrosion, erosion of wet surfaces, erosion of limestone buildings, lake acidification, kills trees

ii. Answers will vary. For example:

Liming acidic soils/waterbodies

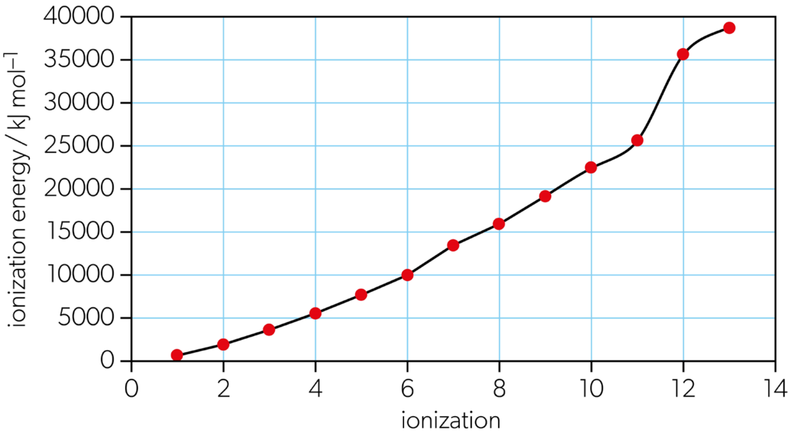
Flue gas desulfurization by alkaline scrubbers

$2Rb(s) + 2H_2O(l) \rightarrow 2RbOH(aq) + H_2(g)$

M1: correct reactants, products and balancing;

M2: correct state symbols

18. a.



M1: correctly labelled axes

M2: increasing trend

b. Cu: $[Ar]\,4s^1\,3d^{10}$

c. Cu^{2+}: $1s^2\,2s^2\,3s^2\,3p^6\,3d^9$

19. Cu^{2+} (in copper(**II**) nitrate) has an incomplete d-subshell

AND

Zn^{2+} (in zinc nitrate) has a full d-subshell;

d-d electron promotion possible in Cu^{2+} thus, absorbing light / not possible in Zn^{2+};

20. a. $f = \dfrac{3.00 \times 10^{8}\,\text{m s}^{-1}}{540 \times 10^{-9}\,\text{m}} = 5.5556 \times 10^{14}\,\text{s}^{-1}$

$\Delta E = (6.63 \times 10^{-34}\text{ J s}) \times (5.5556 \times 10^{14}\text{ s}^{-1}) = 3.68 \times 10^{-19}\text{ J}$ (3 sf)

b. $[CoCl_4]^{2-}$ complex is blue and absorbs longer-wavelength photons / any value between 585 and 647 nm than the $[Co(H_2O)_6]^{2+}$ complex;

Therefore chloride ions cause a smaller ΔE than water molecules;

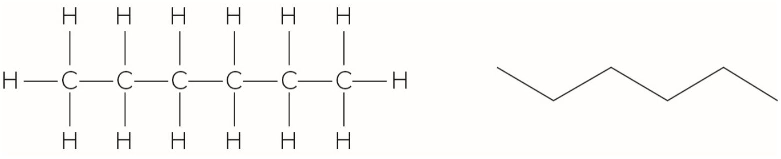
21. The first two *IE* of calcium (590 and 1145 kJ mol^{-1}, respectively) are low, so calcium readily lose its two valence electrons to form Ca^{2+}. The jump from IE_2 to IE_3 (4912 kJ mol^{-1}) is very sharp, so the third electron cannot be removed from calcium by chemical forces.

In contrast, the first four *IE* of titanium (659, 1310, 2653 and 4175 kJ mol^{-1}) are closer to one another, and their increase is more gradual, so titanium can lose two, three or four electrons in chemical reactions.

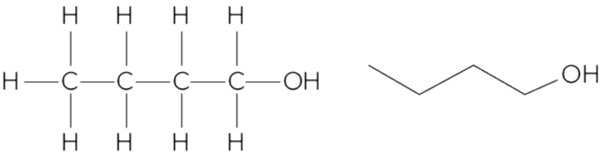
Structure 3.2 – Functional groups: Classification of organic compounds

Practice questions (page 259)

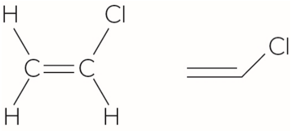
1. a.



b.



c.



2. B

3. D

Practice questions (page 267)

4. C

5. A

6. C

7. D

8. C

Skills questions (page 270)

Answers will vary widely depending on the homologous series chosen and database(s) used. The guidance in Tool 3 should be followed.

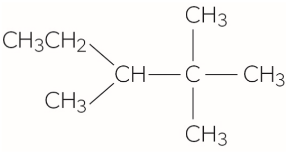
Practice questions (page 273)

9. a. 3-methylhexane

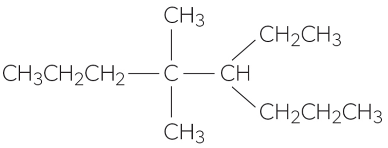
b. 2,4,4-trimethylhexane

c. 3-ethyl-2,4-dimethylhexane

10. a.



b.



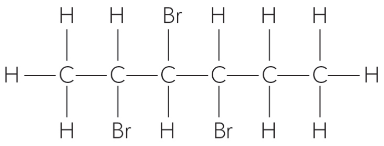
Practice questions (page 275)

11. a. 2,3-dichlorobutane

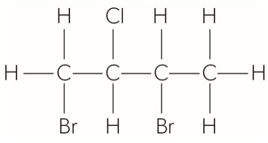
b. 4-chloro-3-iodopent-1-ene

c. 1-bromo-1-chloroethane

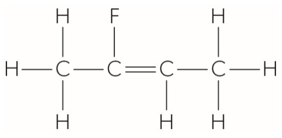
12. a.



b.

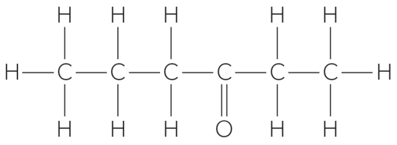


c.

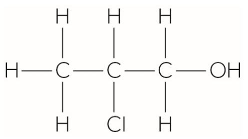


Practice questions (page 278)

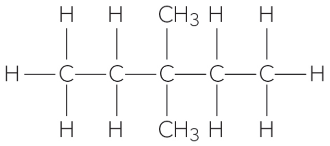
13. a.



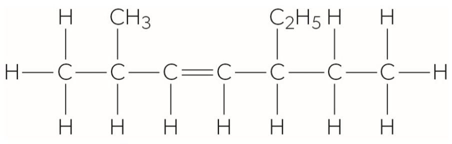
b.



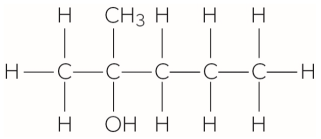
13. c.



d.



e.



14. a. hept-3-ene

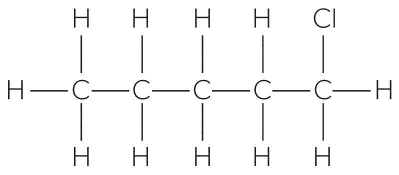
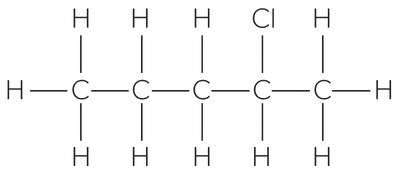
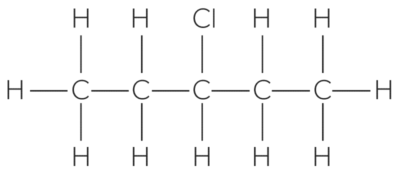
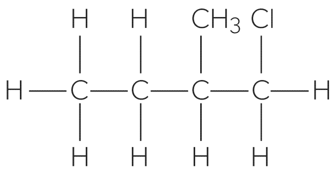
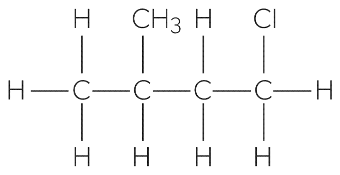
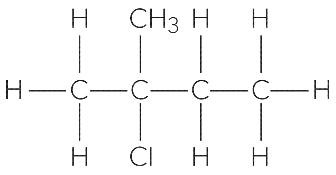
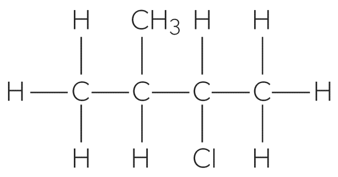
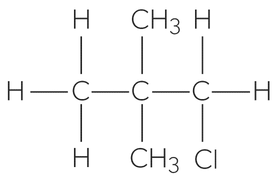
b. 2,4-dimethylpent-2-ene

c. 2,2-dimethylpropan-1-ol

d. 3-methylpentan-2-one

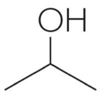
e. 3,3-dimethylbutanal

Activity (page 280)

 1-chloropentane	 2-chloropentane	 3-chloropentane
 1-chloro-2-methylbutane	 1-chloro-3-methylbutane	 2-chloro-2-methylbutane
 2-chloro-3-methylbutane	 1-chloro-2,2-dimethylpropane	

Practice questions (page 282)

15. a.

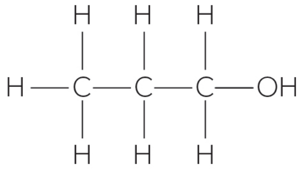
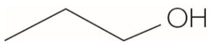
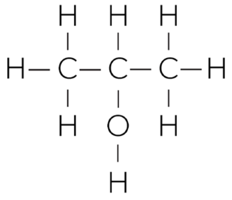
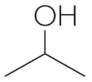
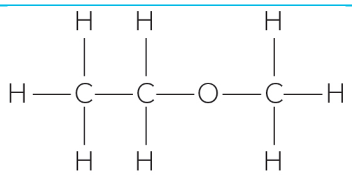
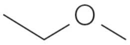


b. The carbon atom that is attached to the hydroxyl group is also attached to two alkyl groups, hence it is a secondary alcohol.

16. B

Skills questions (page 283)

1.

Isomer	Full structural formula	Condensed structural formula	Skeletal formula
propan-1-ol		$CH_3CH_2CH_2OH$	
propan-2-ol		$CH_3CH(OH)CH_3$	
methoxyethane		$CH_3CH_2OCH_3$	

3. Answers will vary depending on visualization software used.

4. Answers will vary. Examples include:

Strengths:

- skeletal formula more practical for large molecules
- 3D models show molecular geometry

Weaknesses:

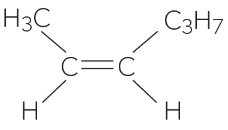
- structural formulae do not necessarily reflect molecular geometry
- condensed structural formula for complex molecules are impractical
- ball-and-stick models represent electrons in bonds as sticks not clouds

5. Answers will vary. For example:

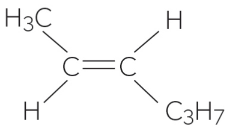
- All three molecules are polar
- Propan-1-ol and propan-2-ol can form hydrogen bonds between their molecules and are therefore more volatile than methoxyethane
- Propan-1-ol and propan-2-ol can be reduced to form propanal and propanone, respectively.
- Propan-1-ol can be further reduced to form propanoic acid

Practice questions (page 286)

17.



cis-hex-2-ene



trans-hex-2-ene

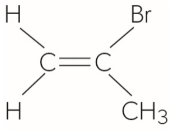
18. a. *trans*-pent-2-ene

b. no *cis–trans* isomerism; pent-1-ene

c. *cis*-hex-3-ene

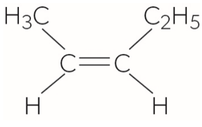
d. no *cis–trans* isomerism; 2-methylpropene

19. a.



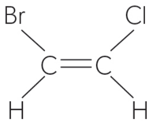
; No

b.



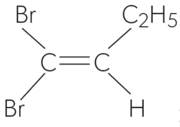
; Yes

c.



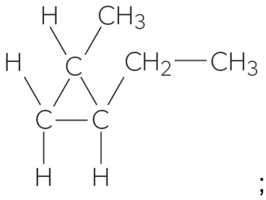
; Yes

d.



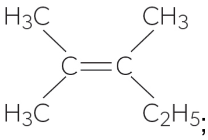
; No

e.



; Yes

f.

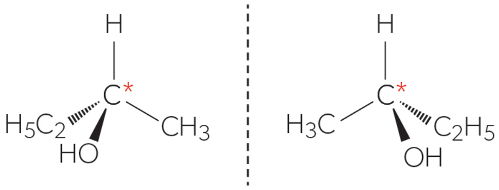


; No

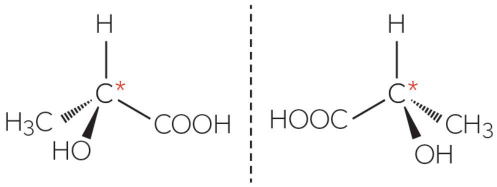
Activity (page 289)

a. The chiral carbon is bonded to four different groups, as shown in **b**.

b. i.



ii.



Skills questions (page 290)

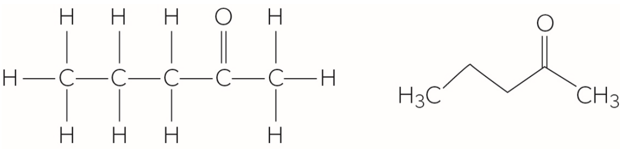
1. Answers may include:

- Concentration of the solution
- Path length
- Intensity of the light source
- Absence of other light sources

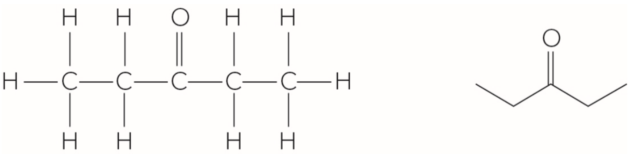
2. Answers will vary according to student plans. Guidance: Option 1 requires a protractor or other device to measure the angle of rotation of one of the polarizing filters. Option 2 requires changing the concentration of the solution in the measuring cylinder but not its volume. Option 3 requires varying the volume of solution in the measuring cylinder but not its concentration. Option 4 involves analysing mixtures of two or more compounds and varying the ratio of each component in the mixture.

Practice question (page 292)

20. a. pentan-2-one



pentan-3-one



b. A is pentan-3-one, $CH_3CH_2COCH_2CH_3$

peak at 29 due to $(CH_3CH_2)^+$

peak at 57 due to $(CH_3CH_2CO)^+$

B is pentan-2-one, $CH_3COCH_2CH_2CH_3$

peak at 43 due to $(CH_3CH_2CH_2)^+$ or $(CH_3CO)^+$

Practice question (page 299)

21. For structure **a** (2-hydroxy-3-methylbutanoic acid):

There are five different hydrogen chemical environments for this compound. The ratio for area under the signals for $H_A : H_B : H_C : H_D : H_E$ is 1 : 1 : 1 : 1 : 6, with the hydrogen atoms being labelled along the chain from the –COOH group.

For structure **b** (3-hydroxy-3-methylbutanoic acid):

There are four different hydrogen chemical environments for this compound. The ratio for area under the signals for $H_A : H_B : H_C : H_D$ is 2 : 1 : 6 : 1, with the hydrogen atoms being labelled along the chain from the –COOH group.

Skills questions (page 303)

2.

Isomer	^{1}H NMR spectrum features	Selection of IR spectrum features	Major mass spectrum peaks
propan-1-ol	4 signals 3:2:2:1 triplet (0.9–1.0 ppm) multiplet (1.3–1.4 ppm) triplet (3.3–3.7 ppm) singlet (1.0–6.0 ppm)	O—H at 3200 to 3600 cm^{-1} (broad) C—H at 2850 to 3090 cm^{-1} C—O at 1050–1410 cm^{-1}	31 (loss of CH_2CH_3)
propan-2-ol	3 signals 6:1:1 doublet (0.9–1.0 ppm) multiplet (3.3–3.7 ppm) singlet (1.0–6.0 ppm)	O—H at 3200 to 3600 cm^{-1} (broad) C—H at 2850 to 3090 cm^{-1} C—O at 1050–1410 cm^{-1}	45 (loss of CH_3)
methoxyethane	3 signals 3:2:3 singlet (3.3–3.7 ppm) quartet (3.3–3.7 ppm) triplet (0.9–1.0 ppm)	C—H at 2850 to 3090 cm^{-1} C—O at 1050–1410 cm^{-1}	60 (molecular ion) 45 (loss of CH_3) 29 (loss of OCH_3)

Chemical shift and IR data values from the IB data booklet, actual values may vary.

End of topic questions (pages 305–307)

1. Answers will depend on the student, but a possible answer might be: The functional group of an organic molecule is used to classify compounds and place them into different classes of organic compounds. It is the functional group that gives a compound its characteristic physical and chemical properties. This consistency of chemical and physical behaviour enables predictions in trends to be made. For example, all alcohols that undergo complete combustion will produce identical products, namely carbon dioxide and water. All carboxylic acids are weak acids that only partially dissociate in aqueous solutions. All ketones will not undergo oxidation reactions, whereas an aldehyde can undergo oxidation, forming a carboxylic acid. The boiling points of a homologous series (e.g. alkanes) progressively increases. This enables us to be able to extrapolate the trend in the data to predict other boiling points. The ability to accurately predict the physical and chemical properties of organic compounds, strengthens our ability to perform scientific research and undertake industrial synthetic reactions.

2. A

3. D

4. D

5. C

6. **a.** no **AND** 2 groups on a carbon in the double bond are the same/hydrogen atoms

   OR

   no **AND** molecule produced by rearranging atoms bonded on a carbon «in the double bond» is the same as the original

   b. yes **AND** has a carbon attached to four different groups

   OR yes **AND** it contains a chiral carbon

   *Accept yes **AND** mirror image of molecule different to original/non-superimposable on original.*

7. **a.** m/z 58: molar/relative molecular mass/weight/M_r is 58 g mol^{-1}/58

   m/z 43: loses methyl/CH_3 fragment

   OR $COCH_3^+$ fragment

   *Do **not** penalize missing charge on the fragments.*

   b. C=O

   Accept carbonyl/C=C.

   c. *Information deduced from ^1H NMR:*

   one signal indicates one hydrogen environment/symmetrical structure

   OR

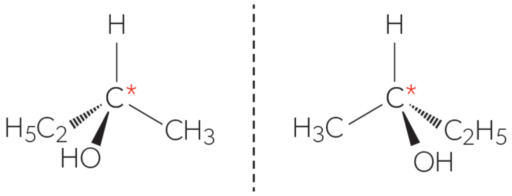
   chemical shift of 2.2 indicates H on C next to the carbonyl

   Compound:

   propanone/CH_3COCH_3

   Accept "one type of hydrogen".

8. **a.**



   b. enantiomers rotate plane of plane-polarized light

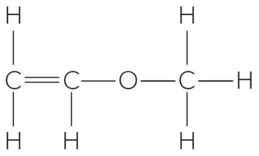
   equal degrees/angles/amounts ***AND*** opposite directions/rotation

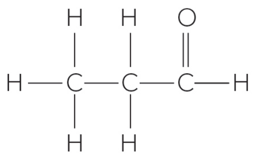
   Accept "optical isomers" for "enantiomers".

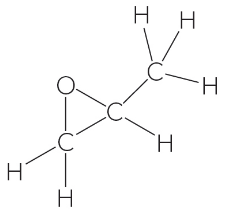
9. a. Compound A contains a carbon-carbon double bond and a hydroxyl group

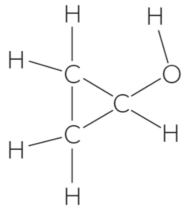
Compound B contains a carbonyl group

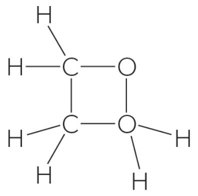
b. Any two of the following:

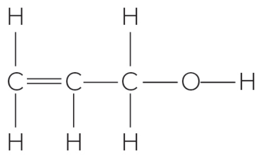


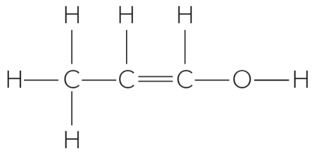












c. Compound B **AND** C=O absorption / 1750 cm^{-1}

Accept any value between 1700–1750 cm^{-1}

OR

Compound B **AND** absence of OH / 3200–3600 cm^{-1} absorption

10. a. two major isotopes with mass numbers 35 and 37

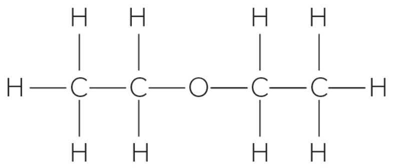
b. diatomic molecule composed of two chlorine-37 atoms

chlorine-37 is the least abundant isotope

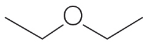
OR

low probability of two ^{37}Cl isotopes occurring in a molecule

11. a.



or



OR

$CH_3CH_2OCH_2CH_3$

b. 2 signals

0.9−1.0 **AND** triplet

3.3−3.7 **AND** quartet

Accept any values in the ranges.

*Award **[1]** for two correct chemical shifts or two correct splitting patterns*