C H E M I S T R Y

2002 NATIONAL QUALIFYING EXAMINATION

Time Allowed
Reading Time: 15 minutes
Examination Time: 120 minutes

INSTRUCTIONS

- This paper is in **two** sections and you must answer each section according to the instructions.

  Section A: Answer **ALL** questions — spend no more than 30 minutes on this section.

  Section B: Apportion your time equally on the questions in this section.

  Question 16 is **compulsory**

  Answer **any two** of Questions 17, 18 or 19

- All answers must be written in the space provided in the answer book.

- Use **blue** or **black** pen to write your answers, pencil is **not** acceptable.

- Rough working must be done only in the indicated areas of the answer book.

- You are not permitted to refer to books, periodic tables or written notes.

- The only permitted aid is a non-programmable electronic calculator.

- Relevant data that may be required for a question will be found on page 2.

DATA

Avogadro constant (N)
   6.02×10^{23} mol^{-1}

1 faraday   96,486 coulombs

1 coulomb   1 A s

Universal gas constant (R)
   8.314 J K^{-1} mol^{-1}
   8.206×10^{-2} L atm K^{-1} mol^{-1}

Planck's constant (h)
   6.626×10^{-34} J s

Standard temperature and pressure (STP)
   273 K and 101.3 kPa
   0°C and 101.3 kPa
   0°C and 1 atm
   0°C and 760 mm Hg

Molar volume of ideal gas at STP
   22.4 L

Velocity of light (c)
   2.998×10^{8} m s^{-1}

Density of water at 25°C
   0.9971 g cm^{-3}

Acceleration due to gravity
   9.81 m s^{-2}

1 newton (N)   1 kg m s^{-1}

1 pascal (Pa)   1 N m^{-1}

$\gamma_{wax/air}$ 35.4 mN m^{-1}

$\gamma_{water/wax}$ 54.0 mN m^{-1}

ATOMIC NUMBERS & RELATIVE ATOMIC MASSES[*]

1	H	1.008	23	V	50.94	45	Rh	102.9	67	Ho	164.9	9	Ac	(227)
2	He	4.003	24	Cr	52.00	46	Pd	106.4	68	Er	167.3	90	Th	232.0
3	Li	6.941	25	Mn	54.94	47	Ag	107.9	69	Tm	168.9	91	Pa	(231)
4	Be	9.012	26	Fe	55.85	48	Cd	112.4	70	Yb	173.0	92	U	238.0
5	B	10.81	27	Co	58.93	49	In	114.8	71	Lu	175.0	93	Np	(237)
6	C	12.01	28	Ni	58.69	50	Sn	118.7	72	Hf	178.5	94	Pu	(244)
7	N	14.01	29	Cu	63.55	51	Sb	121.8	73	Ta	180.9	95	Am	(243)
8	O	16.00	30	Zn	65.38	52	Te	127.6	74	W	183.9	96	Cm	(247)
9	F	19.00	31	Ga	69.72	53	I	126.9	75	Re	186.2	97	Bk	(247)
10	Ne	20.18	32	Ge	72.59	54	Xe	131.3	76	Os	190.2	98	Cf	(251)
11	Na	22.99	33	As	74.92	55	Cs	132.9	77	Ir	192.2	99	Es	(252)
12	Mg	24.31	34	Se	78.96	56	Ba	137.3	78	Pt	195.1	100	Fm	(257)
13	Al	26.98	35	Br	79.90	57	La	138.9	79	Au	197.0	101	Md	(258)
14	Si	28.09	36	Kr	83.80	58	Ce	140.1	80	Hg	200.6	102	No	(259)
15	P	30.97	37	Rb	85.47	59	Pr	140.9	81	Tl	204.4	103	Lw	(260)
16	S	32.07	38	Sr	87.62	60	Nd	144.2	82	Pb	207.2	104	Db	
17	Cl	35.45	39	Y	88.91	61	Pm	(145)	83	Bi	209.0	105	Jt	
18	Ar	39.95	40	Zr	91.22	62	Sm	150.4	84	Po	(209)	106	Rf	
19	K	39.10	41	Nb	92.91	63	Eu	152.0	85	At	(210)	107	Bh	
20	Ca	40.08	42	Mo	95.94	64	Gd	157.3	86	Rn	(222)	108	Hn	
21	Sc	44.96	43	Tc	(98)[†]	65	Tb	158.9	87	Fr	(223)	109	Mt	
22	Ti	47.88	44	Ru	101.1	66	Dy	162.5	88	Ra	226.0			

[*] The relative values given here are to four significant figures.
[†] A value given in parentheses denotes the mass of the longest-lived isotope.

SECTION A

It is intended that candidates devote not more than **30 minutes to this section**. Answer **ALL** fifteen (15) questions in this section. Only one choice is allowed per question and this should be made by clearly crossing the chosen answer box in **the answer book**. If you make a mistake **correct it clearly** so that the examiners can read your answer.

Q1   What is the electronic configuration of the ground state of the aluminium cation, Al^{3+}?

    A $1s^2 2s^2 2p^6 3s^2 3p^1$

    B $1s^2 2s^2 2p^6 3s^2 3p^6$

    C $1s^2 2s^2 2p^6$

    D $1s^2 2s^2 2p^6 3s^2$

    E $1s^2 2s^2 2p^4 3s^2$

Q2   If the percentage of water of crystallization in $CuSO_4.xH_2O$ is 36.1%, what is the value of x?

    A   1

    B   3

    C   4

    D   5

    E   6

Q3   Oxalate ions ($C_2O_4^{2-}$) can be oxidized by permanganate ions (MnO_4^-) according to the two following half equations:

$$C_2O_4^{2-} \rightarrow 2CO_2 + 2e^-$$

$$MnO_4^- + 8H^+ + 5e^- \rightarrow Mn^{2+} + 4H_2O$$
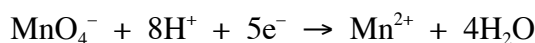
How many moles of MnO_4^- are required to oxidize 1 mole of $C_2O_4^{2-}$?

    A   2.5

    B   0.4

    C   2.0

    D   1.5

    E   5.0

Q4   Carbon dioxide reacts with water to form carbonic acid (H_2CO_3) and is called the acid anhydride of that acid.
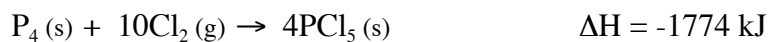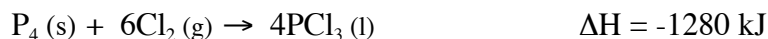
The anhydrides of sulfurous and nitric acids are:

    A SO_3 and NO_2

    B SO_2 and N_2O_5

    C SO_3 and N_2O_5

    D SO_2 and NO_2

    E SO_4^{2-} and NO_2

Q5   A student plans to calculate the molar mass of an unknown gas from the mass of a measured volume of gas at a known temperature and pressure. To how many significant figures should the student report the molar mass if 175.0 mL of the gas weighs 1.0315 g at a temperature of 22 °C and pressure of 742 mmHg?

   A   one

   B   two

   C   three

   D   four

   E   five

Q6   0.0005 moles of metal chloride were dissolved in water and required 60.0 mL of 0.025 M silver nitrate solution to complete precipitation of silver chloride. These results are consistent with a chloride with the formula:

   A MCl

   B M_2Cl

   C MCl_2

   D MCl_3

   E M_2Cl_3

Q7   Which combinations of equal volumes of solution will result in buffer solutions?

   1   0.1 M HCl and 0.1 M NH_3

   2   0.1 M HNO_2 and 0.05 M NaOH

   3   0.05 M HNO_2 and 0.05 NH_3

   A   1 only

   B   2 only

   C   3 only

   D   1 and 3 only

   E   2 and 3 only

Q8   In which compound does manganese have an oxidation number +3?

   A $KMnO_4$

   B $K_2[Mn(CN)_6]$

   C $K_5[Mn(CN)_6]$

   D $MnSO_4$

   E $CsMn(SO_4)_2.12H_2O$

Q9 The number of moles of KOH in 500 mL of solution is to be determined by titrating 10.00 mL portions of the KOH solution with 0.115 M HCl solution. If 18.72 mL of the HCl solution are needed to titrate each 10.00 mL portion of the KOH solution, how many moles of KOH are present in the original solution?

  A   0.00215 mol

  B   0.00430 mol

  C   0.108 mol

  D   0.215 mol

  E   0.115 mol

Q10 Which compound is expected to be the *least* soluble in water?

  A CH_3COOH

  B CH_3COONa

  C $CH_3CH_2NH_2$

  D CH_3CH_2OH

  E CH_3OCH_3

Q11 $^{90}_{232}Th$ is converted to $^{82}_{208}Pb$ by the emission of a series of alpha and beta particles. How many alpha and beta particles are emitted in this process?

	alpha	beta
A	3	2
B	4	8
C	5	2
D	6	4
E	8	8

Q12 The solubility product of silver sulfate is 1.5×10^{-5} mol^3L^{-3}. In a solution in which $[SO_4^{2-}]$ is 2.4×10^{-2} $molL^{-1}$, the maximum $[Ag^+]$, in $molL^{-1}$, is

  A   0.025

  B 6.25×10^{-4}

  C 3.125×10^{-4}

  D 2.5×10^{-4}

  E 6.25×10^{-2}

Q13 In which reaction will an increase in the volume of the container favour the formation of products?

  A $C_{(s)} + H_2O_{(g)} \rightleftharpoons CO_{(g)} + H_2{(g)}$

  B $H_2{(g)} + I_2{(g)} \rightleftharpoons 2HI_{(g)}$

  C $4NH_3{(g)} + 5O_2{(g)} \rightleftharpoons 4NO_{(g)} + 6H_2O_{(l)}$

  D $3O_2{(g)} \rightleftharpoons 2O_3{(g)}$

  E $2NO_{(g)} + O_2{(g)} \rightleftharpoons 2NO_2{(g)}$

Q14 Phosphorus trichloride and phosphorus pentachloride are both used in the industrial preparation of organophosphorus compounds. The enthalpy changes for the preparation of these two chlorides from white phosphorus are given by the equations:

$$P_4 \text{ (s)} + 6Cl_2 \text{ (g)} \rightarrow 4PCl_3 \text{ (l)} \qquad\qquad \Delta H = \text{-1280 kJ}$$

$$P_4 \text{ (s)} + 10Cl_2 \text{ (g)} \rightarrow 4PCl_5 \text{ (s)} \qquad\qquad \Delta H = \text{-1774 kJ}$$

What is the enthalpy change, in kJ, for the reaction $PCl_3 \text{ (l)} + Cl_2 \text{ (g)} \rightarrow PCl_5 \text{ (s)}$?

A -123.5

B -494

C -763.5

D +123.5

E -3054

Q15 Which of the following molecules would be expected to be planar?

1 NH_3

2 XeF_4

3 SF_4

4 ICl_4^-

A 1, 2 and 3 only correct

B 2 and 3 only correct

C 3 and 4 only correct

D 2 and 4 only correct

E all are correct

SECTION B

Candidates are advised that the correct use of significant figures will be taken into consideration when marking answers to these problems. Candidates are also advised that steps to the solution of problems must be clearly explained. Marks will be deducted for untidy and poorly explained answers.
Question 16 is compulsory. You have a choice of answering any two questions of the remaining three questions.

Compulsory question
Candidates should note that for calculations they are required to give answers both as expressions and as computed results. Failure to provide either of these will result in marks being deducted.

Q16   Reduction and oxidation are essential chemical processes that occur constantly. One of the most important oxidising agents is, of course, molecular oxygen itself. Its ability to oxidise a number of transition metal solutions can be a nuisance to chemists, as it often requires them to work under inert atmospheres, such as nitrogen. Aqueous solutions containing iron(II) ions are an important example: atmospheric oxygen slowly oxidises iron(II) to iron(III) in such solutions, itself being converted to water.

(a)   Write suitable balanced half equations for:

   (i) The oxidation of Fe^{2+} to Fe^{3+}; and

   (ii) The reduction of O_2 to H_2O.

(b)   Write a balanced equation for the oxidation of Fe^{2+} by molecular oxygen.

(c)   Would you expect this redox process to be affected by the acidity of the solution of Fe^{2+}? Support your answer.

   Kesan, an eager young chemist, decides to investigate this effect on solutions of iron(II) perchlorate. The bottle of iron(II) perchlorate that he decides to use gives the formula as $Fe(ClO_4)_2.xH_2O$ — the symbol x, he is told, is used because the true value varies from sample to sample and has to be determined. Consequently, Kesan measures out 13.4 g of iron(II) perchlorate, and carefully transfers it to a 200.0 mL volumetric flask, which he fills with deionised water. He then carefully shakes the flask to dissolve the iron(II) perchlorate.

   Realising that Kesan will need to determine the amount of Fe(II) and Fe(III) ions in solution separately, his wise teacher gives him a bottle with the label H_3L. His teacher tells him that the bottle contains an organic ligand which will bind Fe(III) ions strongly according to the formula:

   $$Fe^{3+} \text{ (aq)} + 2H_3L \text{ (aq)} \rightarrow [FeL_2]^{3-} \text{ (aq)} + 6H^+ \text{ (aq)}$$
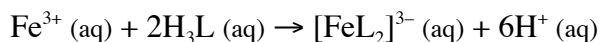
   What makes this ligand particularly useful, however, is that the ligand itself (H_3L) has an intense blue colour while the iron(III) complex ($[FeL_2]^{3-}$) appears as a pale yellow. Moreover, it does not bind iron(II) ions at all. So, the concentration of Fe(III) ions in a solution can be determined by titration with the ligand H_3L even in the presence of Fe(II) ions — the ligand is added to the solution until the faintest blue-green colour persists. Kesan, with the help of his teacher, makes up a large amount of 0.3182 M H_3L solution, which he keeps for later use.

   Question 16 continues on the next page.

Now, Kesan decides to determine the iron(II) concentration in his iron(II) perchlorate solution. He pipettes 20.0 mL of the solution into a clean conical flask. As he only has a method of determining iron(III) concentrations, he first oxidises the iron(II) quantitatively to iron(III) by adding excess acidified potassium dichromate ($K_2Cr_2O_7$) to the solution (the dichromate anion is reduced in the process to chromium(III) ions – these too bind H_3L in exactly the same manner as iron(III) anions). He then titrated this solution with the 0.3182 M H_3L solution he prepared earlier, and found that he needed 30.20 mL of this solution to reach the endpoint.

(d)   What is the oxidation state of chromium in potassium dichromate?

(e)   Give a balanced equation for the oxidation of iron(II) to iron(III) by the dichromate anion.

(f)   What does the persistence of a blue-green colour at the titration endpoint indicate?

(g)   Calculate the concentration of Fe(II) in the original solution of iron(II) perchlorate. Assume that there is no Fe(III) contaminating the solution.

(h)   Calculate the value of x in the sample of iron(II) perchlorate sample used to make up the solution.

Using this titration technique, Kesan feels confident he can determine the concentration of Fe(III) ions in any solution. So, to determine the effect of oxygen on his solution of iron(II) perchlorate, he pipettes two more 20.0 mL aliquots of the solution into four clean conical flasks, labelled 1 and 2. He titrates sample 1 with the ligand solution immediately, and finds that the blue-green colour is present even when he adds one drop of the solution. Sample 2 he leaves for one week before titrating, and finds that it requires 11.35 mL of ligand solution to reach its endpoint.

(i)   Explain the meaning of the result of the titration of sample 1.

(j)   Calculate the concentration of Fe(III) ions in sample 2 at the time of the titration.

(k)   Calculate the amount of Fe(II) ions remaining in the solution as a fraction of the original Fe(II) ion concentration.

(l)   Suppose Kesan had left sample 2 for another week and then titrated it with the ligand solution. Would you expect the titre to be greater than, less than or equal to 22.70 mL in volume?

Q17 **Lattice energy** (U_o) is the standard enthalpy change accompanying the formation of an ionic solid from gaseous ions,

i.e. M^+ (g) + X^- (g) → MX (s).

For example, Na^+ (g) + Cl^- (g) → NaCl (s).
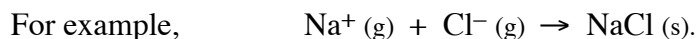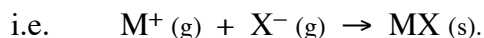
The reaction is always exothermic and hence U_o <u>always</u> has a negative sign. Lattice energies cannot be measured directly but can be determined indirectly from enthalpy data using a **Born-Haber cycle**.

EXAMPLE: The lattice energy of NaCl can be determined by constructing a thermochemical cycle (known as a Born-Haber cycle) containing known thermodynamic quantities (except for U_o) as shown below:
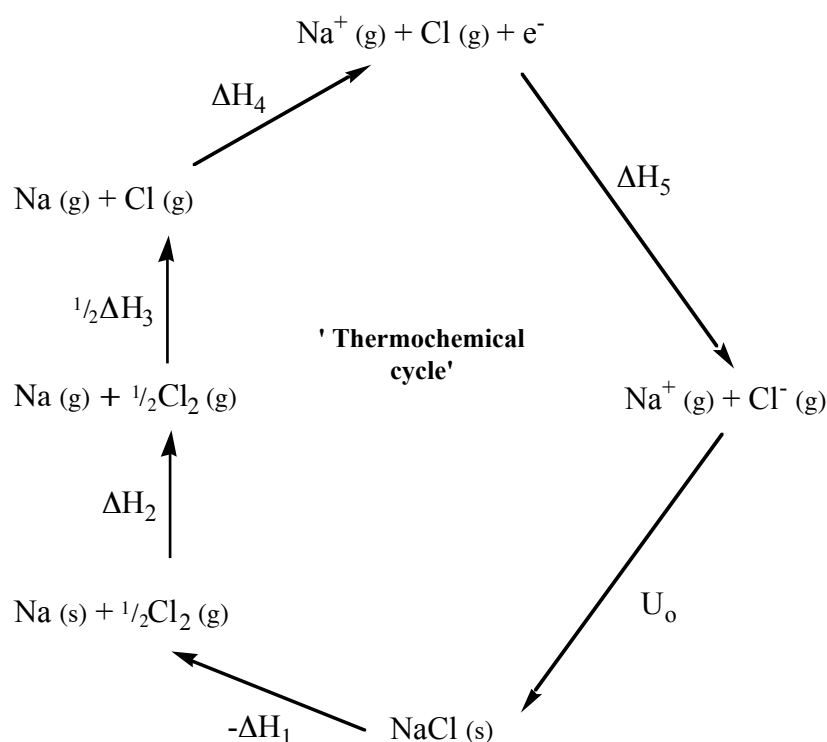
Where

ΔH_1 = enthalpy of formation of NaCl (i.e. ΔH for the reaction Na (s) + $^1/_2Cl_2$ (g) → NaCl (s));

ΔH_2 = enthalpy of sublimation of Na (i.e. ΔH for the reaction Na (s) → Na (g));

ΔH_3 = bond dissociation energy for Cl_2 (i.e. ΔH for the reaction Cl_2 (g) → 2Cl (g));

ΔH_4 = first ionization energy of Na (i.e. ΔH for the reaction Na (g) → Na^+ (g) + e^-); and

ΔH_5 = electron affinity of Cl (i.e. ΔH for the reaction Cl (g) + e^- → Cl^- (g)).

Question 17 continues on the next page.

In a thermochemical cycle $\Sigma \, \Delta H = 0$ (Hess's law),

i.e. $-\Delta H_1 \; + \; \Delta H_2 \; + \; \frac{1}{2}\Delta H_3 \; + \; \Delta H_4 \; + \; \Delta H_5 \; + \; U_o \; = 0.$

Here all of the terms except U_o can be measured experimentally. Substituting the appropriate values of ΔH_{1-5} from the Table of **Thermodynamic Data** gives:

$-\Delta H_1 \; + \; \Delta H_2 \; + \; \frac{1}{2}\Delta H_3 \; + \; \Delta H_4 \; + \; \Delta H_5 \; + \; U_o \; = 0$

i.e. $411 + \; 108 \; + \; \frac{1}{2}(242) \; + \; 496 \; - \; 356 \; + \; U_o \; = 0$

i.e. $U_o = -780 \text{ kJ mol}^{-1}$ for NaCl (s)

Thermodynamic Data			
Enthalpy of formation	-411 kJmol^{-1} (NaCl)	-561.5 kJmol^{-1} (NaF)	-1090 kJmol^{-1} (MgF$_2$)
First ionisation energy	496 kJmol^{-1} (Na)	738 kJmol^{-1} (Mg)	
Second ionisation energy	4560 kJmol^{-1} (Na)	1450 kJmol^{-1} (Mg)	
Enthalpy of sublimation	108 kJmol^{-1} (Na)	141 kJmol^{-1} (Mg)	
Electron affinity	-356 kJmol^{-1} (Cl)	-332 kJmol^{-1} (F)	
Bond dissociation energy	242 kJmol^{-1} (Cl$_2$)	155 kJmol^{-1} (F$_2$)	

(a)   Construct a Born - Haber cycle for NaF (s).

(b)   Determine the lattice energy for NaF (s) by using the appropriate data in the above Table.

(c)   Construct a Born - Haber cycle for MgF$_2$ (s).

(d)   Determine the lattice energy for MgF$_2$ (s) by using the appropriate data in the above Table.

Q18 Isomerism is an extremely important concept in chemistry. Compounds are said to be *isomeric* if they have the same molecular formula but have different structures. Isomerism can be divided into the following categories:

- Structural (or constitutional) isomerism whereby the isomers have different bond connectivities.

- Stereoisomerism (or configurational) whereby the isomers have the same bond connectivities but differ in the spatial arrangement of the atoms.

For example, C_4H_{10} is the molecular formula for both butane and 2-methylpropane, shown below:

butane   2-methylpropane
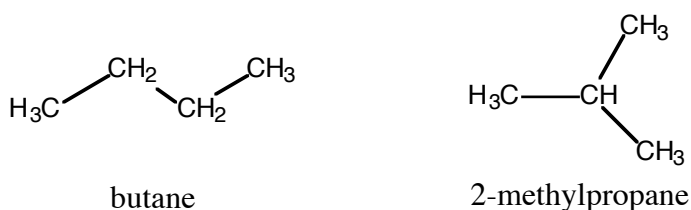
Butane and 2-methylpropane are constitutional isomers.

(a)   Draw all constitutional isomers of compounds with the molecular formula C_5H_{12}.

(b)   Draw all the constitutional isomers of compounds with the molecular formula C_4H_9Br.

A common example of stereoisomerism is a carbon atom with four different substituents (known as a *stereogenic* or *asymmetric* carbon), such as in bromochloroiodomethane. The four substituents are oriented tetrahedrally about the carbon atom, which gives rise to two non-superposable mirror image forms, known as enantiomers (shown below, labelled molecules A and B). The dashed bond (·····нιιιΙΙΙ) indicates a bond pointing into the page, the wedged bond (◢██) indicates a bond pointing out of the page and normal bonds (———) are in the plane of the page.

molecule A   molecule B
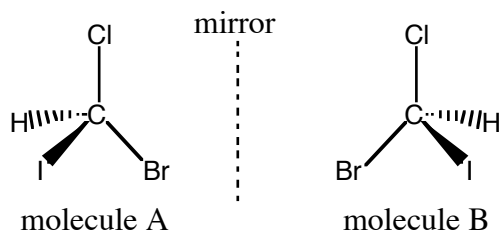
Molecules A and B are not identical: you can see this by rotating molecule A 180° about the C—Cl bond.

molecule A   molecule A   molecule B
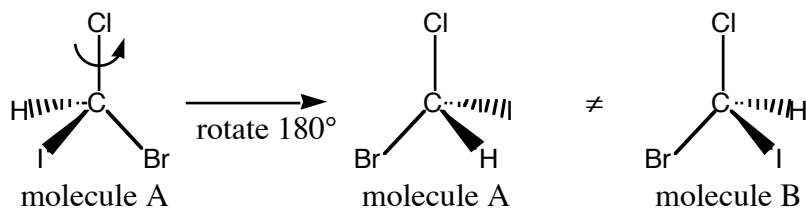
Enantiomers (non-superposable mirror-image forms) are distinguished from one another by the designations (R) and (S), depending on their configuration in 3D space. This is decided using the following **RULES**.

RULE 1   Rank the four atoms bound to the stereogenic carbon in order of decreasing atomic number

For example with CHBrClI, $I > Br > Cl > H$.

RULE 2   Put the 4th ranked substituent facing into the page, and draw arrows from the 1st-ranked to the 2nd-ranked to the 3rd-ranked substituents, then back to the 1st-ranked. If these arrows are drawn in a clockwise sense the molecule is designated (R), if anticlockwise it is designated (S).

Thus for molecule B of bromochloroiodomethane, we can see that it must be the (R) enantiomer:
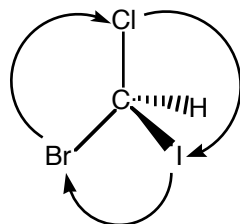
(R)-bromochloroiodomethane

(c)   Using the partial structures on the answer sheet, draw and name the two enantiomers of 1-bromo-1-chloroethane ($CH_3—CHClBr$).

RULE 3   If two or more of the atoms bound to the stereogenic carbon are the same then the next atoms out are compared.

For 2-chlorobutane (one enantiomer shown below with stereochemistry), clearly Cl is the highest ranking substituent, and H is the lowest ranking. We then have to decide whether the CH_3 or CH_2CH_3 group ranks higher.
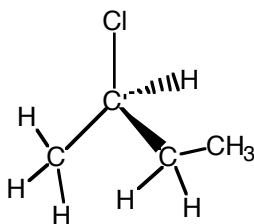

one enantiomer of 2-chlorobutane

Using **RULE 3** above, the next atoms out in the CH_3 group are 3 hydrogens (HHH); the next atoms out in the CH_2CH_3 group are one carbon and two hydrogens (CHH). C>H so CHH>HHH, and thus $CH_2CH_3>CH_3$

Thus for 2-chlorobutane the order is $Cl>CH_2CH_3>CH_3>H$.

(d)   Draw the two enantiomers of 2-chlorobutane (one enantiomer is shown above) and name them fully.

(e)   Draw the two enantiomers of propane-1,2-diol (shown below without stereochemistry) and name them.
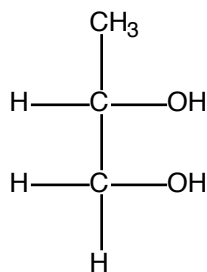
propane-1,2-diol

When two or more stereogenic centres are present in a molecule things can get a little more complicated. Butane-2,3-diol (shown below without stereochemistry) is an example of this.
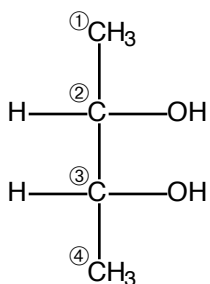
butane-2,3-diol

(f) (i) Draw all possible forms of butane-2,3-diol, and assign each stereocentre as R or S.

   (ii) What is interesting about the (2R,3S)- and (2S,3R)- forms?

(g)   What is the **maximum** number of stereoisomers possible for a molecule with n stereogenic centres?

(h)(i) How many constitutional isomers of $C_5H_{11}Br$ are there?

   (ii) How many of these will exist as enantiomeric pairs?

Q19 Relevant data for this question can be found on the data sheet.

Consider the interface of a liquid and its vapour. Molecules in the bulk of the liquid will interact with a larger number of neighbouring molecules than those on the surface. The surface molecules will have higher energy, and it takes energy input to increase surface area. The force required is known as *surface tension*, or γ, and has units of N m^{-1}.

(a) (i) Are the intermolecular forces attractive or repellent? Why?

   (ii) Which liquid will have the greater surface tension – water or n-hexane?

Surface tension means that curved interfaces (for example, a droplet or a bubble) may behave differently to the liquid/gas behaviour in bulk. Think about what happens when a bubble, or cavity, containing vapour and air, is formed in a liquid.

(b) What effect will surface tension have?

A spherical interface will be stable when the force of surface tension is balanced by a greater pressure inside the sphere. The pressure difference is given by:

$$\Delta P = \frac{2\gamma}{r} \qquad\qquad (\mathbf{1})$$

Where r is the radius of curvature, γ is surface tension at the liquid/vapour interface, and pressure is measured in Pascals.

(c) In the following diagram, all valves are originally closed. When valves B and C are opened, what will happen to bubbles B and C?
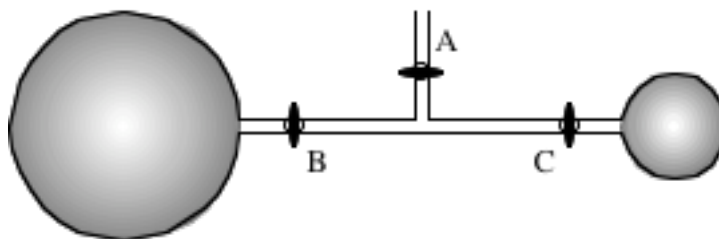
(d) Given that increased pressure in a liquid also increases its vapour pressure, explain why water vapour may not form clouds (collections of small water droplets) in the atmosphere even when condensation is thermodynamically favoured. Why do you think that 'seeding' with dust particles or ions may help?

Another phenomenon related to curvature is capillary action. If a fine glass tube is inserted vertically into a dish of water, the water will rise to a higher level within the tube.
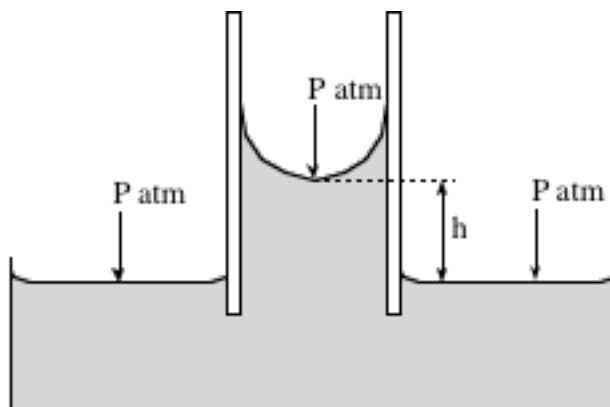
If we consider the interface to be a hemisphere and use equation (**1**), then the pressure of water beneath the tube has value

$$P = P_{atm} - \frac{2\gamma}{r}$$

However, the pressure at the foot of the column must equal the atmospheric pressure experienced by the bulk surface. Therefore the water rises up the capillary until the weight of the column equals the difference in pressure due to surface tension effects. That is,

$$\frac{2\gamma}{r} = \rho gh \qquad\qquad (2)$$

here ρ is the density of water in kgm^{-3}, g is gravitational constant and h is the height of the column in metres.

(e)   If at 25°C water rises 7.36 cm in a capillary of radius 0.20 mm, what will its surface tension at this temperature be?

Note that in a perfectly hemispherical meniscus, the 'contact angle' which water makes with the sides of the glass tube will be 0°. This will not always be the case. Equation (**2**) can be generalised to:

$$\frac{2\gamma \cos\theta}{r} = \rho gh$$

For all $0° \le \theta \le 90°$, we say that the liquid 'wets' the solid – it crosses it spontaneously. This will not always be the case.

(f) (i) What does it say about the relative strengths of the adhesive forces between the liquid and the tube, and the cohesive forces among liquid molecules, if the contact angle is greater than 90° – that is, the meniscus curves outwards?

   (ii) In such a case, where would the relative liquid level within the capillary lie?

(g)   One example of such behaviour is the waterproof nature of ducks. The fine barbels of a duck's feathers are coated with wax which makes a contact angle with water of 105°. Assuming that the gaps between barbels have a radius of 20 micrometres, and can be thought of as spherical, what pressure is needed to force water into a duck's feathers at 25°C? [Use your answer to (e), above, and any other relevant data].