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International Baccalaureate®
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CHEMISTRY
HIGHER LEVEL
PAPER 2

Candidate session number

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Tuesday 8 May 2012 (afternoon)

2 hours 15 minutes

Examination code

2	2	1	2	–	6	1	0	8

INSTRUCTIONS TO CANDIDATES

- Write your session number in the boxes above.
- Do not open this examination paper until instructed to do so.
- Section A: answer all questions.
- Section B: answer two questions.
- Write your answers in the boxes provided.
- A calculator is required for this paper.
- A clean copy of the ***Chemistry*** *Data Booklet* is required for this paper.
- The maximum mark for this examination paper is *[90 marks]*.

0136

SECTION A

*Answer **all** questions. Write your answers in the boxes provided.*

1. Propanone reacts with bromine in acidic solution according to the following equation.

$$CH_3COCH_3(aq) + Br_2(aq) \xrightarrow{H^+(aq)} BrCH_2COCH_3(aq) + HBr(aq)$$

A student investigated the kinetics of this reaction using data logging equipment. Her data are shown below.

	A	B	C	D	E	F
1		**Initial concentration / mol dm^{-3}**				
2	**Experiment**	**[CH_3COCH_3] ± 0.001**	**[Br_2] ± 0.0001**	**[H^+] ± 0.0001**	**Time for colour to fade / s ± 1**	**Rate of reaction / mol dm^{-3} s^{-1}**
3	1	0.200	0.0100	0.0500	250	4.00×10^{-5}
4	2	0.400	0.0100	0.0500	125	8.00×10^{-5}
5	3	0.200	0.0200	0.0500	500	4.00×10^{-5}
6	4	0.200	0.0100	0.1000	125	8.00×10^{-5}
7	5	0.400	0.0050	0.0500	63	X
8						

(a) (i) Identify the reagent the student used to monitor the rate of reaction. *[1]*

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(ii) Calculate the rate of reaction for Experiment 5 and comment on the precision of your result. *[2]*

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(This question continues on the following page)

(Question 1 continued)

(iii) Determine the percentage uncertainty in the calculated rate for Experiment 4. *[2]*

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(b) (i) Deduce the order of reaction with respect to CH_3COCH_3, Br_2 and H^+. *[3]*

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(ii) Deduce the rate expression for the reaction. Calculate the rate constant and state its units. *[3]*

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(This question continues on the following page)

(Question 1 continued)

(c) The student proposed the following mechanism for this reaction.

$$Br_2 \rightarrow 2Br\bullet \qquad \textit{Slow}$$

$$2Br\bullet + CH_3COCH_3 \rightarrow BrCH_2COCH_3 + HBr \qquad \textit{Fast}$$

Comment on whether or not the order with respect to bromine supports this hypothesis. *[2]*

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2. In 1921 Thomas Midgley discovered that the addition of a lead compound could improve the combustion of hydrocarbons in automobile (car) engines. This was the beginning of the use of leaded gasoline (petrol).

The percentage composition, by mass, of the lead compound used by Midgley is shown below.

	Pb	**C**	**H**
Mass composition / %	64.052	29.703	6.245

(a) (i) Determine the empirical formula of the lead compound. *[3]*

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(ii) Leaded gasoline has been phased out because the lead(IV) oxide, PbO_2, produced as a side product in the combustion reaction, may cause brain damage in children.

0.01 mol of Midgley's lead compound produces 0.01 mol of lead(IV) oxide. Deduce the molecular formula of Midgley's compound. *[1]*

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(iii) Determine the equation for the complete combustion of Midgley's compound. *[2]*

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(This question continues on the following page)

(Question 2 continued)

(b) The combustion of unleaded gasoline still produces pollution with both local and global consequences. Identify **one** exhaust gas which causes local pollution and **one** exhaust gas which causes global pollution. *[2]*

Local pollutant:

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Global pollutant:

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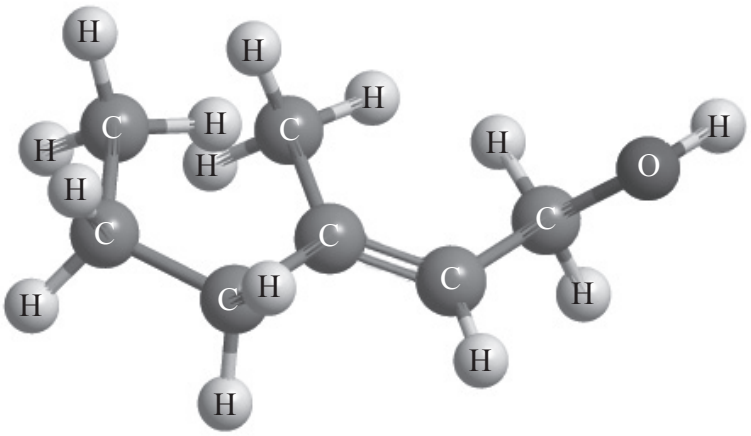
3. Compound **X** (shown below) is produced by bacteria living in human armpits and is thought to be partly responsible for unpleasant body smells.

(a) Bromine water can be used to test for the presence of one of the functional groups in **X**. Identify this functional group and describe the colour change observed. *[2]*



X

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(b) The other functional group changes when **X** is refluxed with acidified excess potassium dichromate(VI) to produce a compound **Y**.

(i) Identify the functional group present in **Y** but not in **X**. *[1]*

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(ii) State the type of reaction that **X** undergoes to form **Y**. *[1]*

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(This question continues on the following page)

(Question 3 continued)

(c) A different compound is produced if excess **X** is heated with acidified potassium dichromate(VI) and the product **Z** is distilled off as it forms.

(i) Identify the functional group present in **Z** but not in **X**. *[1]*

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(ii) Predict the order of increasing boiling point of the compounds **X**, **Y** and **Z** and explain your answer. *[3]*

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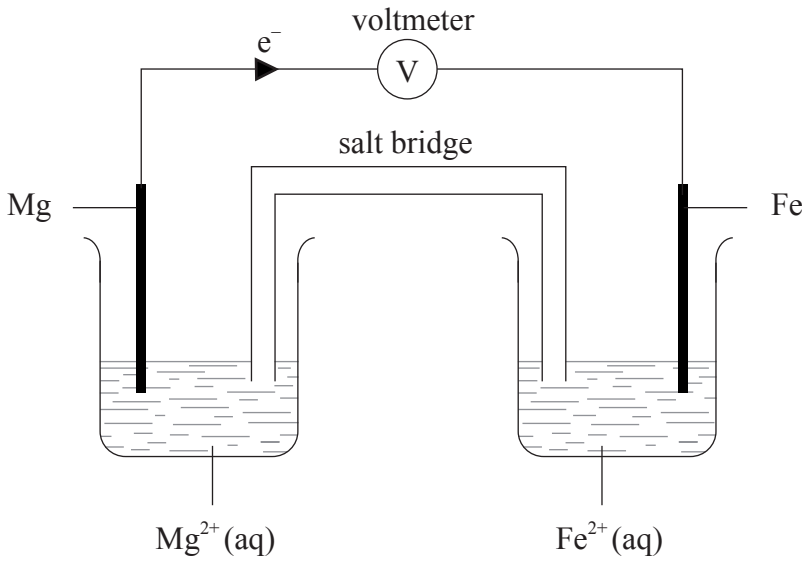
4. Chemical energy can be converted to electrical energy in the voltaic cell below.



(a) State the half-equation which describes the change at the Mg electrode and deduce which metal is the positive electrode (cathode) of the cell. *[2]*

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(b) Deduce the equation for the overall reaction occurring in the cell. *[1]*

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(This question continues on the following page)

(Question 4 continued)

(c) (i) Define the term *standard electrode potential*. *[1]*

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(ii) Calculate the standard cell potential ($E^{\ominus}$), in V, for the spontaneous reaction in (b), using Table 14 of the Data Booklet. *[1]*

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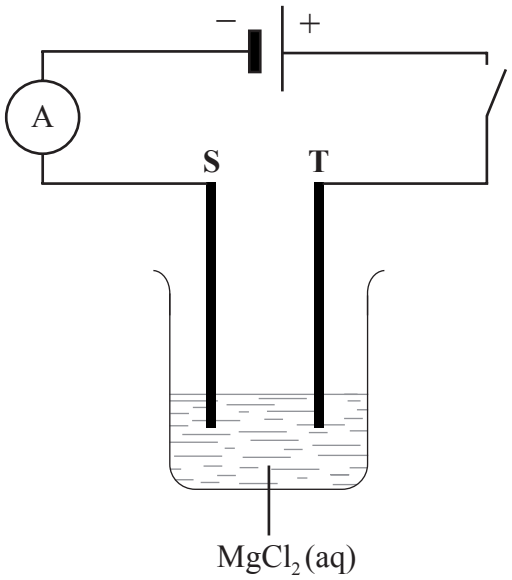
(Question 4 continued)

(d) A different chemical change occurs when a saturated aqueous solution of magnesium chloride is electrolysed using inert electrodes, **S** and **T**, in the circuit below.



Different gases are produced at the electrodes **S** and **T**.

(i) State the half-equations for the reactions at each electrode. *[2]*

S: . . . . . .

T: . . . . . .

(ii) Determine the mole ratio in which the gases are formed. *[1]*

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(This question continues on the following page)

(Question 4 continued)

(iii) Suggest how the experimental conditions could be changed to produce the two gases at a higher rate. *[1]*

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(iv) Another gas is produced when $MgCl_2$ is at a lower concentration. State the name of this gas and deduce the half-equation for this reaction. *[2]*

Name:

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Equation:

. . . . . .

SECTION B

*Answer **two** questions. Write your answers in the boxes provided.*

5. Ethane, C_2H_6, and disilane, Si_2H_6, are both hydrides of group 4 elements with similar structures but with different chemical properties.

(a) (i) Deduce the Lewis (electron dot) structure for Si_2H_6 showing all valence electrons. *[1]*

(ii) State and explain the H–Si–H bond angle in Si_2H_6. *[2]*

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(iii) Identify the type of hybridization shown by the silicon atoms in Si_2H_6. *[1]*

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(This question continues on the following page)

(Question 5 continued)

(iv) State which of the bonds, Si–H or C–H, is more polar. Explain your choice. *[2]*

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(v) Predict, with an explanation, the polarity of the two molecules. *[2]*

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(vi) Explain why disilane has a higher boiling point than ethane. *[2]*

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(Question 5 continued)

(b) Disilane undergoes complete oxidation to form silicon dioxide and water.

$$2Si_2H_6(g)+7O_2(g) \rightarrow 4SiO_2(s) + 6H_2O(l)$$

(i) The standard enthalpy of formation of the silicon compounds is given below.

	$\Delta H_f^{\ominus}$ / kJ mol^{-1}
$Si_2H_6(g)$	+80
$SiO_2(s)$	–911

Calculate the standard enthalpy change, in kJ, for this reaction using these data together with Table 12 of the Data Booklet. *[3]*

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(ii) Calculate the standard enthalpy change, in kJ, for the corresponding combustion reaction of 2 moles of ethane, using Table 12 of the Data Booklet. *[1]*

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(This question continues on the following page)

(Question 5 continued)

(iii) Compare the structure and bonding in carbon dioxide and silicon dioxide. *[3]*

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(c) Disilane reacts with hydrogen to produce silane, SiH_4.

$$Si_2H_6(g) + H_2(g) \rightarrow 2SiH_4(g)$$

Use values from Table 10 of the Data Booklet to calculate the enthalpy change, $\Delta H^{\ominus}$, for this reaction. *[3]*

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(Question 5 continued)

(d) Silicon tetrachloride, $SiCl_4$, is a volatile colourless liquid first prepared by Jöns Jakob Berzelius in 1823.

(i) Suggest an approximate pH value for the solution formed by adding the chloride to water and explain your answer. State the chemical equation for the reaction that takes place. *[3]*

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(ii) Explain why the aqueous solution formed in (d) (i) conducts electricity whereas liquid silicon tetrachloride does not. *[2]*

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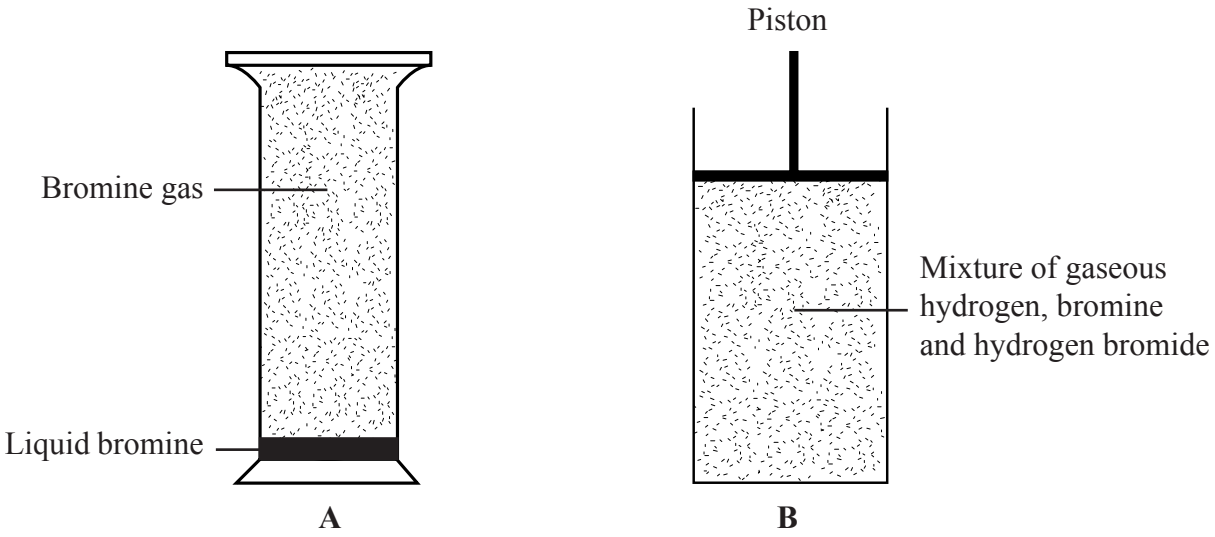
6. Consider the two equilibrium systems involving bromine gas illustrated below.



(a) State equations to represent the equilibria in **A** and **B** with $Br_2(g)$ on the left-hand side in both equilibria. *[2]*

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(b) (i) Describe what you would observe if a small amount of liquid bromine is introduced into **A**. *[1]*

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(This question continues on the following page)

(Question 6 continued)

(ii) Predict what happens to the position of equilibrium if a small amount of hydrogen is introduced into **B**. *[1]*

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(iii) State and explain the effect of increasing the pressure in **B** on the position of equilibrium. *[2]*

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(c) (i) Deduce the equilibrium constant expression, K_c, for the equilibrium in **B**. *[1]*

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(ii) State the effect of increasing $[H_2]$ in **B** on the value of K_c. *[1]*

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(This question continues on the following page)

(Question 6 continued)

(d) (i) Hydrogen bromide forms a strong acid when dissolved in water whereas hydrogen fluoride forms a weak acid. Distinguish between the terms *strong acid* **and** *weak acid*. State equations to describe the dissociation of each acid in aqueous solution. *[3]*

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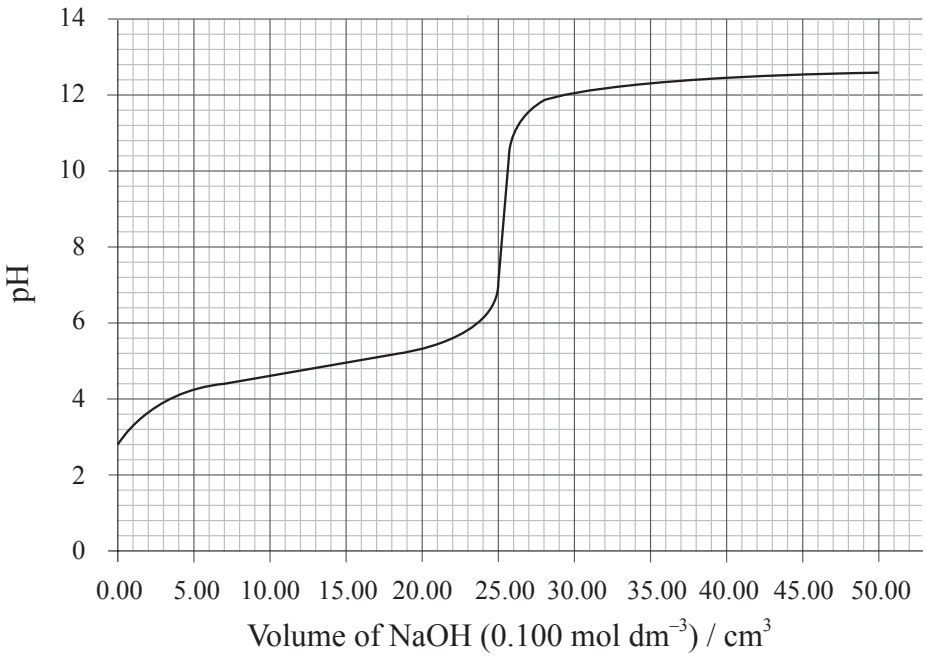
(Question 6 continued)

(ii) A student titrated 25.00 cm^3 of a 0.100 mol dm^{-3} solution of hydrofluoric acid, HF (aq), with 0.100 mol dm^{-3} NaOH (aq). Some of his data are presented below.

	A	B
1		
2	**Volume of NaOH (0.100 mol dm^{-3}) / cm^3**	**pH**
3	0.00	2.88
4	0.50	3.08
5	1.00	3.39
6	1.50	3.57
7	2.00	3.71
8	2.50	3.82
9	3.00	3.90
10	3.50	3.98
11	4.00	4.05
12	4.50	4.11
13	5.00	4.17
14	5.50	4.22
15	6.00	4.27
16	6.50	4.32
17	7.00	4.36
18	7.50	4.40
19	8.00	4.44
20	8.50	4.48
21	9.00	4.52
22	9.50	4.56
23	10.00	4.59
24	10.50	4.63
25	11.00	4.66
26	11.50	4.70
27	12.00	4.73
28	12.50	4.77
29	13.00	4.80
30	13.50	4.84
31	14.00	4.87



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(Question 6 continued)

Two different data points can be used to determine a value for the pK_a of HF (aq). Identify the data points and determine the pK_a using two different calculations. *[6]*

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(iii) Identify an indicator which could be used to find the equivalence point of the titration using Table 16 of the Data Booklet and explain your choice. *[2]*

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(Question 6 continued)

(e) When bromine dissolves in water, 1 % of the original bromine molecules react according to the following equation.

$$Br_2(aq) + H_2O(l) \rightleftharpoons HOBr(aq) + HBr(aq)$$

(i) Deduce the oxidation numbers of bromine in the reactant **and** products. *[2]*

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(ii) Explain the changes in the oxidation numbers of bromine. *[1]*

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(iii) Estimate the magnitude of K_c for this reaction. Choose your value from the following options: *[1]*

$K_c = 0$ $K_c < 1$ $K_c = 1$ $K_c > 1$

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(This question continues on the following page)

(Question 6 continued)

(f) Fluorine reacts with water to produce oxygen.

$$2F_2(g) + 2H_2O(l) \rightarrow 4HF(g) + O_2(g)$$

(i) Identify the oxidizing agent in the reaction. *[1]*

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(ii) 100 cm^3 of fluorine gas is added to water. Calculate the volume of oxygen produced at the same temperature and pressure. *[1]*

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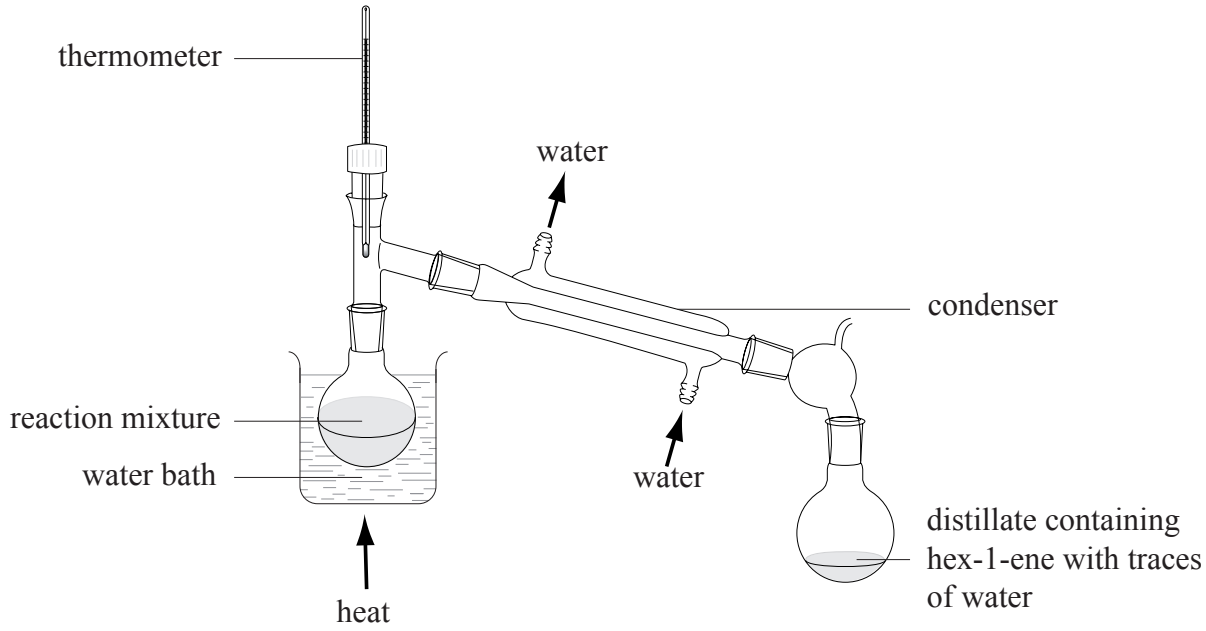
7. A student prepared hex-1-ene, C_6H_{12}, from hexan-1-ol, $C_6H_{13}OH$, by a dehydration reaction.

$$C_6H_{13}OH\,(l) \rightarrow C_6H_{12}\,(l) + H_2O\,(l)$$

The apparatus for this preparation is shown below. The reaction mixture contains 5.00 g of hexan-1-ol and an excess of concentrated sulfuric acid, which removes the water from the organic compound.



The distillate was dried to obtain 2.62 g of hex-1-ene.

(a) (i) Determine the amount, in mol, of hexan-1-ol present in the reaction mixture. *[2]*

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(This question continues on the following page)

(Question 7 continued)

(ii) Calculate the percentage yield of hex-1-ene produced. *[2]*

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(iii) Another student repeated the experiment and reported a yield of 5.24 g of organic product. Comment on this result. *[2]*

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(b) Hex-1-ene can also be produced from the reaction between 1-bromohexane and concentrated aqueous sodium hydroxide or ethanolic sodium hydroxide with the reaction being heated under reflux. Describe the mechanism of this reaction using curly arrows to represent the movement of electron pairs. *[4]*

(This question continues on the following page)

(Question 7 continued)

(c) (i) Unlike 1-bromohexane, 2-bromohexane exists as a pair of optically active isomers. Draw diagrams to show the relationship between the two isomers of 2-bromohexane. *[2]*

(ii) Outline briefly an experimental technique which could be used to distinguish the two isomers in (c) (i). *[2]*

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(d) Identify the type of isomerism present in hex-2-ene. *[1]*

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(Question 7 continued)

(e) Both hex-2-ene and hex-1-ene can be converted to hexane by a reaction with hydrogen in the presence of a nickel catalyst.

(i) Deduce the names of three isomers of hexane. *[3]*

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(ii) Identify the compound with the molecular formula C_6H_{14} which has the highest boiling point and explain your choice. *[3]*

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(Question 7 continued)

(f) Hexane reacts with chlorine to form different products. The reactions can be represented by the following equation, where R is an alkyl chain.

$$R–H + Cl_2 \rightarrow R–Cl + HCl$$

Describe the stepwise mechanism by giving **one** equation for each step and state the essential condition in the initiation step. *[4]*

Initiation:

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Essential condition:

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Propagation:

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Termination:

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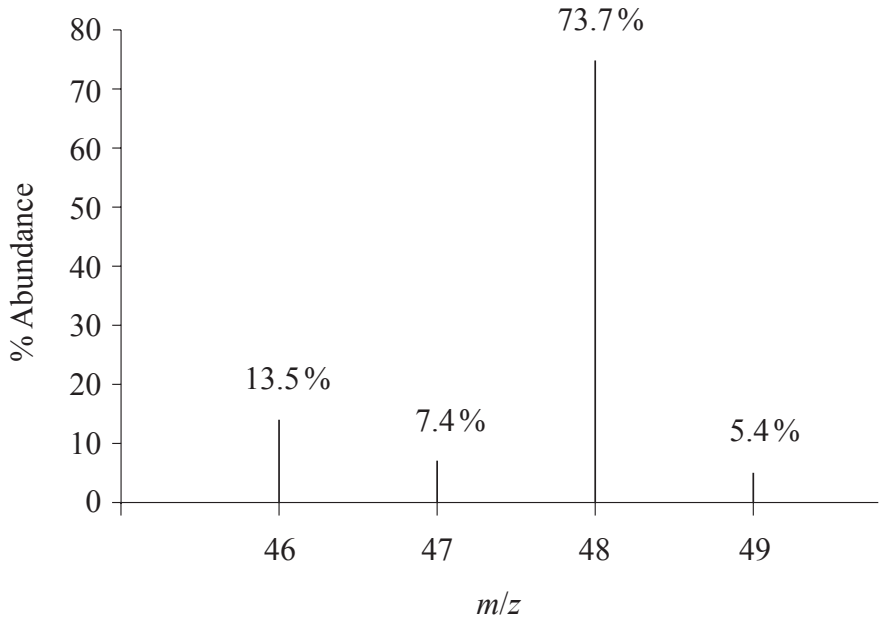
8. The element titanium is present in meteorites.

(a) A meteorite was analysed using mass spectrometry (MS). The mass spectrum below shows the relative abundances of the different titanium isotopes.



(i) The first and last processes in mass spectrometry are vaporization and detection. State the names of the other three processes in the order in which they happen and outline how each occurs. *[5]*

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(Question 8 continued)

(ii) Define the term *relative atomic mass* (A_r). *[1]*

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(iii) Calculate the relative atomic mass of this sample of titanium, giving your answer to one decimal place. *[2]*

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(iv) Explain why a very low pressure is maintained inside the mass spectrometer. *[1]*

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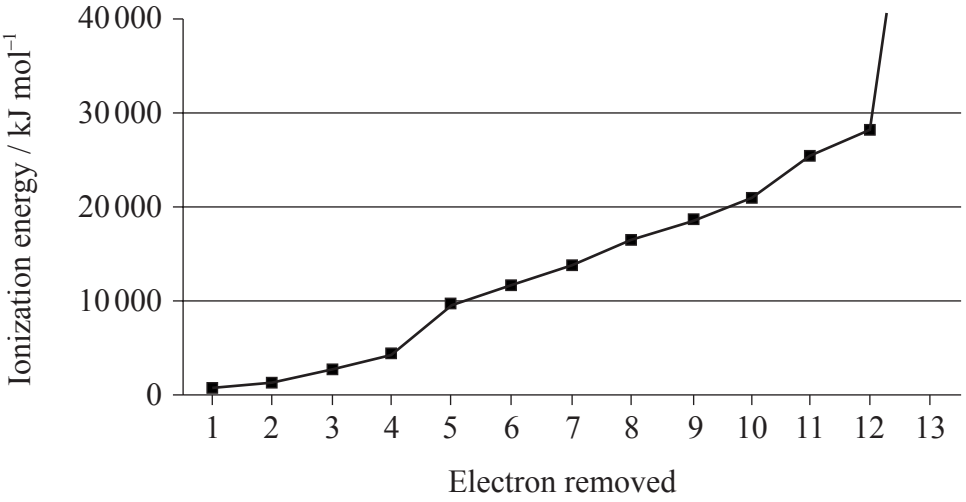
(Question 8 continued)

(b) The successive ionization energies of titanium are shown below.



(i) State the **full** electron configuration of an atom of titanium and identify the sub-level from which the electron is removed when the 1st ionization energy is measured. *[2]*

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(ii) Explain why there are relatively large differences between the 4th and 5th, **and** between the 10th and 11th ionization energies. *[3]*

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(This question continues on the following page)

(Question 8 continued)

(iii) Predict the **three** stable oxidation numbers of titanium ions in aqueous solution. *[1]*

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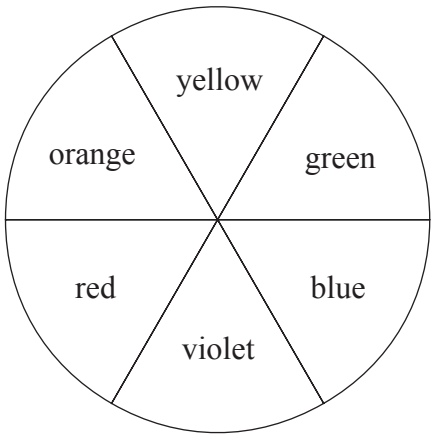
(iv) One characteristic of the d-block (transition) elements, like titanium, is that they form coloured compounds. With reference to the colour wheel below, explain why $Ni^{2+}(aq)$ is green but $Sc^{3+}(aq)$ is colourless. *[5]*



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(Question 8 continued)

(c) Successive ionization energy data provides evidence for the existence of energy levels in atoms. Other evidence is provided by the hydrogen emission spectrum.

(i) Describe the appearance of the visible emission spectrum of hydrogen. *[2]*

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(ii) Explain how this spectrum is related to the electron energy levels in a hydrogen atom. *[3]*

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