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CHEMISTRY
STANDARD LEVEL
PAPER 2

Candidate session number

SPECIMEN PAPER

Examination code

1 hour 15 minutes

INSTRUCTIONS TO CANDIDATES

- Write your session number in the boxes above.
- Do not open this examination paper until instructed to do so.
- Answer all 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 *[50 marks]*.

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

1. Two IB students carried out a project on the chemistry of bleach.

(a) The bleach contained a solution of sodium hypochlorite, NaClO(aq). The students determined experimentally the concentration of hypochlorite ions, ClO^-, in the bleach.

Experimental procedure:

- The bleach solution was first diluted by adding 25.00 cm^3 of the bleach to a 250 cm^3 volumetric flask. The solution was filled to the graduation mark with deionized water.

- 25.00 cm^3 of this solution was then reacted with excess iodide in acid.

$$ClO^-(aq) + 2I^-(aq) + 2H^+(aq) \rightarrow Cl^-(aq) + I_2(aq) + H_2O(l)$$

- The iodine formed was titrated with 0.100 mol dm^{-3} sodium thiosulfate solution, $Na_2S_2O_3(aq)$, using starch indicator.

$$I_2(aq) + 2S_2O_3^{2-}(aq) \rightarrow 2I^-(aq) + S_4O_6^{2-}(aq)$$

The following data were recorded for the titration:

	First titre	**Second titre**	**Third titre**
Final burette reading of 0.100 mol dm^{-3} $Na_2S_2O_3(aq)$ (in $cm^3 \pm 0.05$)	23.95	46.00	22.15
Initial burette reading of 0.100 mol dm^{-3} $Na_2S_2O_3(aq)$ (in $cm^3 \pm 0.05$)	0.00	23.95	0.00

(i) Calculate the volume, in cm^3, of 0.100 mol dm^{-3} $Na_2S_2O_3(aq)$ required to react with the iodine to reach the end point. *[1]*

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(This question continues on the following page)

(Question 1 continued)

(ii) Calculate the amount, in mol, of $Na_2S_2O_3(aq)$ that reacts with the iodine. *[1]*

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(iii) Calculate the concentration, in $mol\,dm^{-3}$, of hypochlorite ions in the **diluted** bleach solution. *[1]*

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(iv) Calculate the concentration, in $mol\,dm^{-3}$, of hypochlorite ions in the **undiluted** bleach solution. *[1]*

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(This question continues on the following page)

(Question 1 continued)

(b) Some of the group 17 elements, the halogens, show variable valency.

(i) Deduce the oxidation states of chlorine and iodine in the following species. *[1]*

NaClO:

. . . . . .

I_2:

. . . . . .

(ii) Deduce, with a reason, the oxidizing agent in the reaction of hypochlorite ions with iodide ions in part (a). *[1]*

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(iii) From a health and safety perspective, suggest why it is not a good idea to use hydrochloric acid when acidifying the bleach. *[1]*

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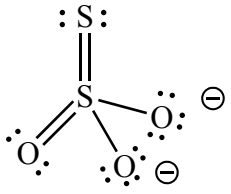
(This question continues on the following page)

(Question 1 continued)

(iv) The thiosulfate ion, $S_2O_3^{2-}$, is an interesting example of oxidation states. The sulfur atoms can be considered to have an oxidation state of +6 on one atom and –2 on the other atom. Discuss this statement in terms of your understanding of oxidation state. *[2]*



Lewis (electron dot) structure of thiosulfate

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(Question 1 continued)

(c) The various changes that have been made to the definitions of oxidation and reduction show how scientists often broaden similarities to general principles.

Combustion is also a redox type of reaction.

With reference to the combustion reaction of methane, explore **two** different definitions of oxidation, choosing one which is valid and one which may be considered not valid.

$$CH_4(g) + 2O_2(g) \rightarrow CO_2(g) + 2H_2O(l)$$ *[2]*

Valid:

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. . . . . .
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Not valid:

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(d) (i) State the **condensed** electron configuration of sulfur. *[1]*

. . . . . .

(ii) Deduce the orbital diagram of sulfur, showing all the orbitals present in the diagram. *[1]*

2. One of the main constituents of acid deposition is sulfuric acid, H_2SO_4. This acid is formed from the sulfur dioxide pollutant, SO_2.

A mechanism proposed for its formation is:

$$HO\bullet(g) + SO_2(g) \rightarrow HOSO_2(g)$$
$$HOSO_2(g) + O_2(g) \rightarrow HOO\bullet(g) + SO_3(g)$$
$$SO_3(g) + H_2O(l) \rightarrow H_2SO_4(aq)$$

(a) (i) State what the symbol (•) represents in the species shown in this mechanism. *[1]*

. . . . . .
. . . . . .

(ii) Draw one valid Lewis (electron dot) structure for each molecule below. *[2]*

Molecule	**Lewis (electron dot) structure**
SO_2	
H_2O	

(This question continues on the following page)

(Question 2 continued)

(iii) Deduce the name of the electron domain geometry and the molecular geometry for each molecule. *[2]*

	Electron domain geometry	**Molecular geometry**
SO_2	. . . . .	. . . . .
H_2O	. . . . .	. . . . .

(iv) Deduce the bond angles in SO_2 and H_2O. *[1]*

SO_2:

. . . . . .

H_2O:

. . . . . .

(This question continues on the following page)

(Question 2 continued)

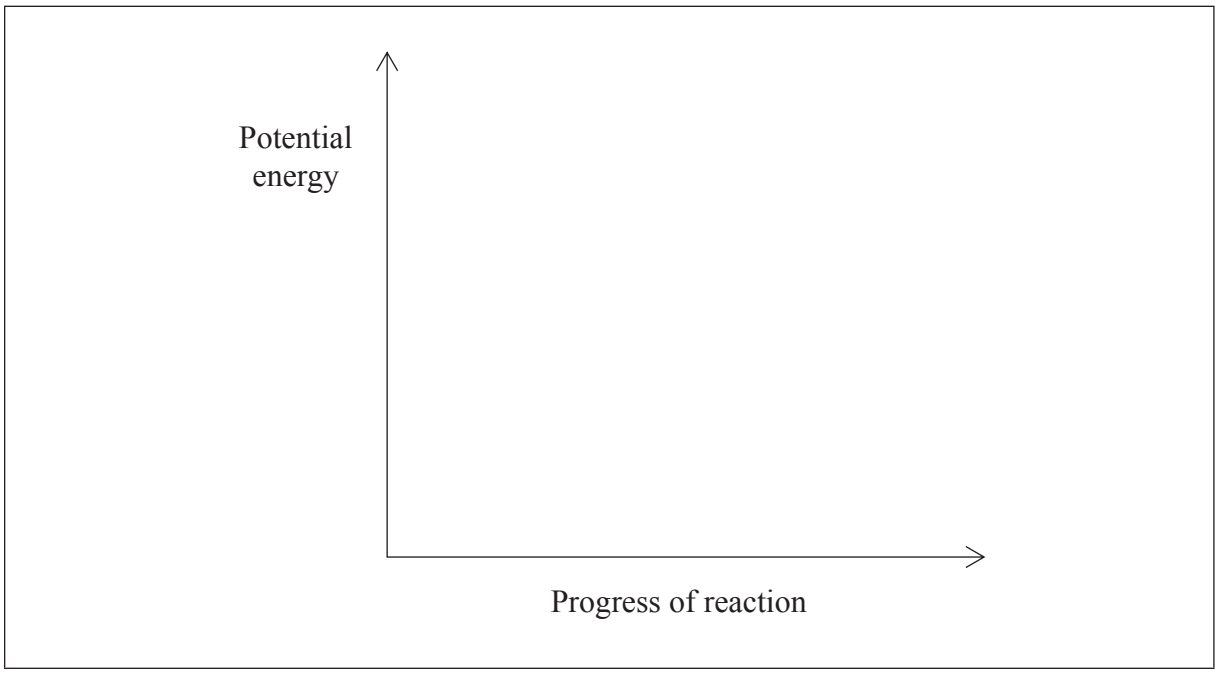
(v) Consider the following equilibrium between the two oxides of sulfur, sulfur dioxide and sulfur trioxide:

$$2SO_2(g) + O_2(g) \rightleftharpoons 2SO_3(g) \qquad \Delta H = -198\,kJ$$

Predict, with a reason, in which direction the position of equilibrium will shift for each of the changes listed below. *[3]*

Change	Shift	Reason
Increase in temperature	. . . . .	. . . . .
Increase in pressure	. . . . .	. . . . .
Addition of a catalyst to the mixture	. . . . .	. . . . .

(vi) Sketch the potential energy profile for the forward reaction in part (v) to show the effect of a catalyst on the activation energy, E_{act}. *[2]*



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(Question 2 continued)

(vii) Sulfuric acid, H_2SO_4, can be described as a Brønsted–Lowry acid. State what you understand by this description. *[1]*

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(viii) The hydrogen sulfate anion, HSO_4^-, is amphiprotic, so can act as an acid or a base. In the reaction of HSO_4^- with the hydronium cation, H_3O^+, identify the two species acting as bases.

$$HSO_4^-(aq) + H_3O^+(aq) \rightleftharpoons H_2SO_4(aq) + H_2O(l)$$ *[1]*

. . . . . .

(ix) Other compounds present in acid rain are formed from nitrogen dioxide, NO_2. Formulate an equation for the reaction of nitrogen dioxide with water. *[1]*

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3. Many automobile manufacturers are developing vehicles that use hydrogen as a fuel.

(a) Suggest why such vehicles are considered to cause less harm to the environment than those with internal combustion engines. *[1]*

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(b) Hydrogen can be produced from the reaction of coke with steam:

$$C(s) + 2H_2O(g) \rightarrow 2H_2(g) + CO_2(g)$$

Using information from section 12 of the data booklet, calculate the change in enthalpy, ΔH, in $kJ\,mol^{-1}$, for this reaction. *[2]*

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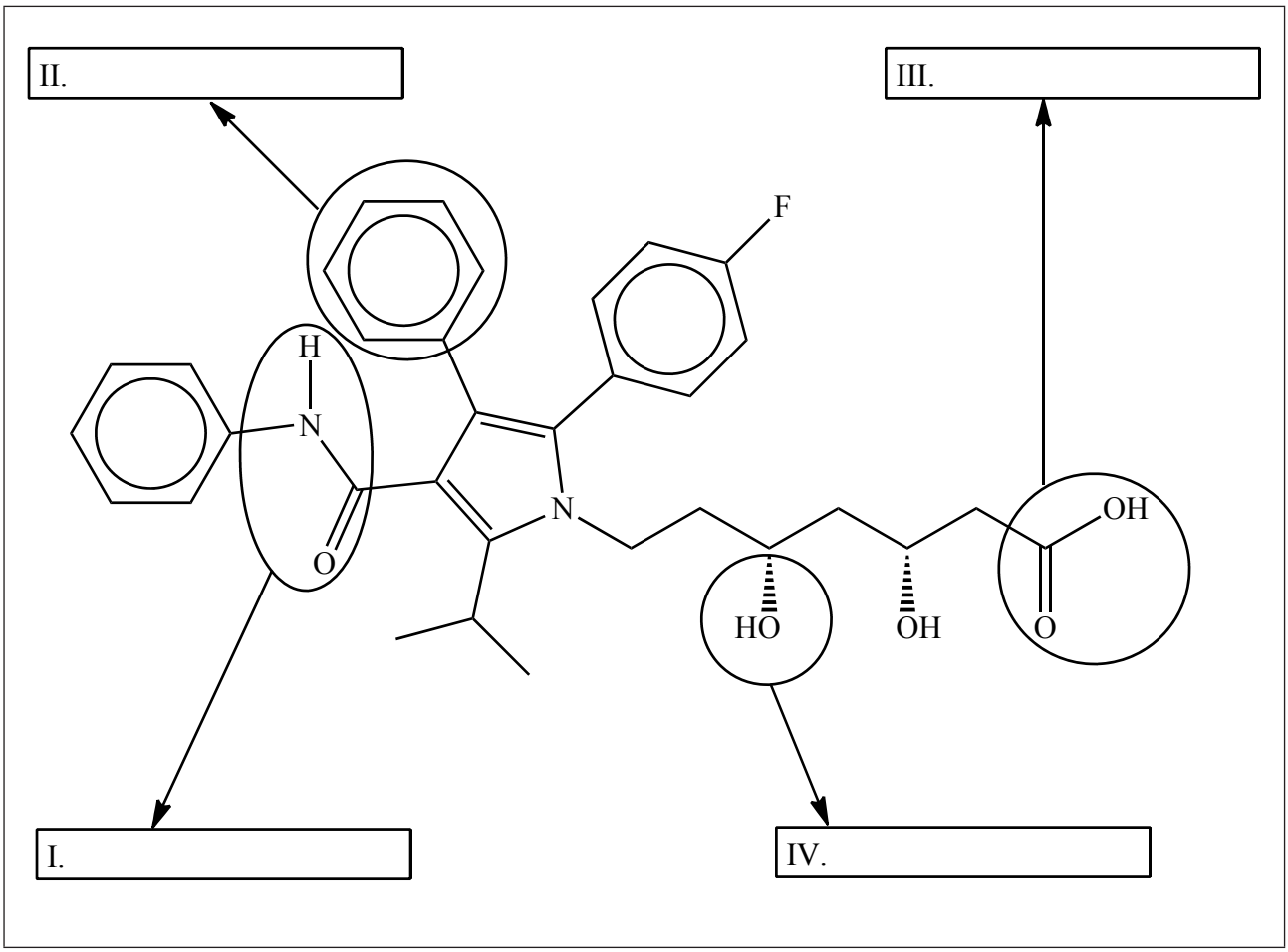
4. The biopharmaceutical industry is now a global contributor to the world economy.

(a) Atorvastatin, a drug used to lower cholesterol, recently gained attention from the global media.

Atorvastatin has the structure shown below.



Identify the **four** functional groups, I, II, III and IV. *[2]*

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(Question 4 continued)

(b) Bute, a painkiller used on horses, has caused widespread concern recently because analytical tests showed that it entered the food chain through horse meat labelled as beef. The drug is suspected of causing cancer.

(i) Analysis of a sample of bute carried out in a food safety laboratory gave the following elemental percentage compositions by mass:

Element	Percentage
C	73.99
H	6.55
N	9.09
O	Remainder

Calculate the empirical formula of bute, showing your working. *[3]*

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(ii) The molar mass, M, of bute, is 308.37 g mol^{-1}. Calculate the molecular formula. *[1]*

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(This question continues on the following page)

(Question 4 continued)

(iii) Deduce the degree of unsaturation (index of hydrogen deficiency – IHD) of bute. *[1]*

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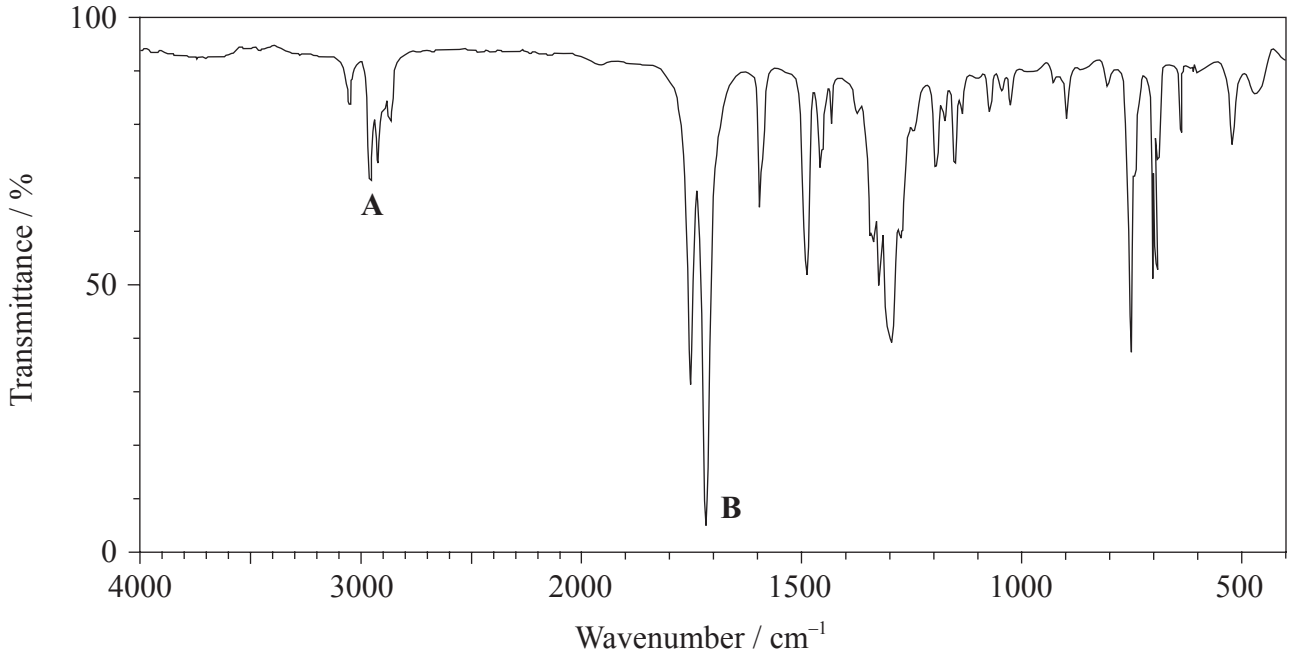
. . . . . .

(iv) The infrared (IR) spectrum of bute is shown below.



[Source: SDBS web: www.sdbs.riodb.aist.go.jp (National Institute of Advanced Industrial Science and Technology, 2014)]

Using information from section 26 of the data booklet, identify the bonds corresponding to **A** and **B**. *[1]*

A: . . . . . .

B: . . . . . .

(This question continues on the following page)

(Question 4 continued)

(v) Based on analysis of the IR spectrum, predict, with an explanation, one bond containing oxygen and one bond containing nitrogen that could **not** be present in the structure. *[2]*

Bond containing oxygen not present in structure:

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Bond containing nitrogen not present in structure:

. . . . . .

Explanation:

. . . . . .

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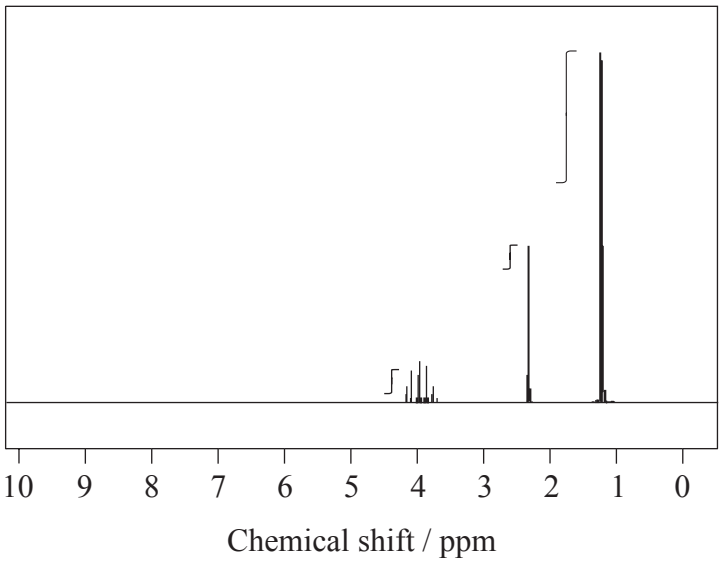
(Question 4 continued)

(c) An alcohol, **X**, of molecular formula C_3H_8O, used as a disinfectant in hospitals, has the following ^{1}H NMR spectrum.



[Source: SDBS web: www.sdbs.riodb.aist.go.jp (National Institute of Advanced Industrial Science and Technology, 2014)]

The three peaks in the ^{1}H NMR spectrum of **X** have chemical shift values centred at $\delta =$ 4.0, 2.3 and 1.2 ppm.

(i) From the integration trace, estimate the ratio of hydrogen atoms in different chemical environments. *[1]*

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(ii) Deduce the full structural formula of **X**. *[1]*

(This question continues on the following page)

(Question 4 continued)

(iii) **Y** is an isomer of **X** containing a different functional group. State the condensed structural formula of **Y**. *[1]*

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(iv) Compare and contrast the expected mass spectra of **X** and **Y** using section 28 of the data booklet. *[2]*

One similarity:

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One difference:

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(Question 4 continued)

(v) Both **X** and **Y** are soluble in water. Deduce whether or not both **X** and **Y** show hydrogen bonding with water molecules, representing any hydrogen bonding present by means of a diagram. *[2]*

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(vi) **X** reacts with acidified potassium dichromate(VI) solution to form **Q** and with ethanoic acid to form **W**. Deduce the condensed structural formula of **Q** and **W**. *[2]*

Q:

. . . . . .

W:

. . . . . .

(This question continues on the following page)

(Question 4 continued)

(vii) Apply IUPAC rules to state the name of compound **Q**. *[1]*

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Please **do not** write on this page.

Answers written on this page
will not be marked.