SOTA SCHOOL OF THE ARTS SINGAPORE

CHEMISTRY
Higher Level
Paper 1
Preliminary Examinations

Wednesday 31 August 2022

1 hour

INSTRUCTIONS TO CANDIDATES

- Write your name, class and index number in the blanks below.
- Do not open this examination paper until instructed to do so.
- Answer all the questions.
- For each question, choose the answer you consider to be the best and indicate your choice on the answer sheet provided.
- The periodic table is provided for reference on page 2 of this examination paper.
- The maximum mark for this examination paper is **[40 marks]**.

Name: _____

Class: _____

Index: _____

40

The Periodic Table

	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18
1	1 H 1.01																	2 He 4.00
2	3 Li 6.94	4 Be 9.01											5 B 10.81	6 C 12.01	7 N 14.01	8 O 16.00	9 F 19.00	10 Ne 20.18
3	11 Na 22.99	12 Mg 24.31											13 Al 26.98	14 Si 28.09	15 P 30.97	16 S 32.07	17 Cl 35.45	18 Ar 39.95
4	19 K 39.10	20 Ca 40.08	21 Sc 44.96	22 Ti 47.87	23 V 50.94	24 Cr 52.00	25 Mn 54.94	26 Fe 55.85	27 Co 58.93	28 Ni 58.69	29 Cu 63.55	30 Zn 65.38	31 Ga 69.72	32 Ge 72.63	33 As 74.92	34 Se 78.96	35 Br 79.90	36 Kr 83.90
5	37 Rb 85.47	38 Sr 87.62	39 Y 88.91	40 Zr 91.22	41 Nb 92.91	42 Mo 95.96	43 Tc (98)	44 Ru 101.07	45 Rh 102.91	46 Pd 106.42	47 Ag 107.87	48 Cd 112.41	49 In 114.82	50 Sn 118.71	51 Sb 121.76	52 Te 127.60	53 I 126.90	54 Xe 131.29
6	55 Cs 132.91	56 Ba 137.33	57 † La 138.91	72 Hf 178.49	73 Ta 180.95	74 W 183.84	75 Re 186.21	76 Os 190.23	77 Ir 192.22	78 Pt 195.08	79 Au 196.97	80 Hg 200.59	81 Tl 204.38	82 Pb 207.2	83 Bi 208.98	84 Po (209)	85 At (210)	86 Rn (222)
7	87 Fr (223)	88 Ra (226)	89 ‡ Ac (227)	104 Rf (267)	105 Db (268)	106 Sg (269)	107 Bh (270)	108 Hs (269)	109 Mt (278)	110 Ds (281)	111 Rg (281)	112 Cn (285)	113 Unt (286)	114 Uuq (289)	115 Uup (288)	116 Uuh (293)	117 Uus (294)	118 Uuo (294)

Atomic number
Element
Relative atomic mass

†	58 Ce 140.12	59 Pr 140.91	60 Nd 144.24	61 Pm (145)	62 Sm 150.36	63 Eu 151.96	64 Gd 157.25	65 Tb 158.93	66 Dy 162.50	67 Ho 164.93	68 Er 167.26	69 Tm 168.93	70 Yb 173.05	71 Lu 174.97
‡	90 Th 232.04	91 Pa 231.04	92 U 238.03	93 Np (237)	94 Pu (244)	95 Am (243)	96 Cm (247)	97 Bk (247)	98 Cf (251)	99 Es (252)	100 Fm (257)	101 Md (258)	102 No (259)	103 Lr (262)

1. 20.0 cm^3 of 0.20 mol dm^{-3} aqueous sodium bromide, NaBr (aq), was mixed with 30.0 cm^3 of 0.30 mol dm^{-3} aqueous potassium bromide, KBr (aq). What is the concentration of bromide ions in the final solution?

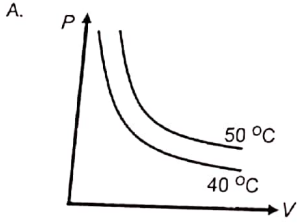
A. 0.10 mol dm^{-3}
B. 0.25 mol dm^{-3}
C. 0.26 mol dm^{-3}
D. 0.50 mol dm^{-3}

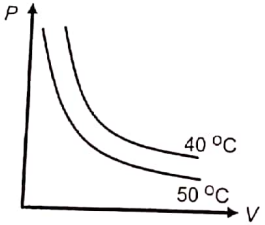
2. What is the volume of carbon dioxide formed when 2.5 dm^3 of propane is burnt in 20.0 dm^3 of oxygen?

$$C_3H_8(g) + 5O_2(g) \rightarrow 3CO_2(g) + 4H_2O(g)$$

A. 3.0 dm^3
B. 5.0 dm^3
C. 7.5 dm^3
D. 12.0 dm^3

3. Which graph shows the relationship between the pressure, *P*, and volume, *V*, of an ideal gas at 40 °C and 50 °C?

A.


B.


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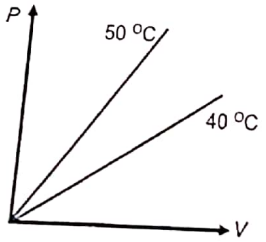
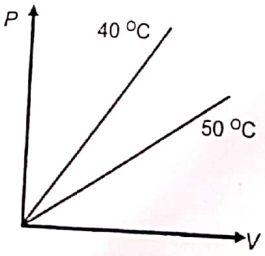
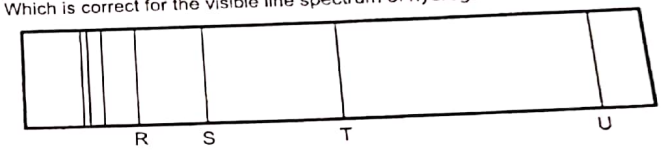


D.


4. Which is correct for the visible line spectrum of hydrogen shown below?



A. Line U has a higher energy than line T.
B. Line T has a lower frequency than line S.
C. Line R has a longer wavelength than line S
D. All the lines are caused by transitions that end at n = 1 level.

5. An element is in group 17 and period 4 of the periodic table. How many electrons are in the highest occupied principal (main) energy level of an atom of this element?

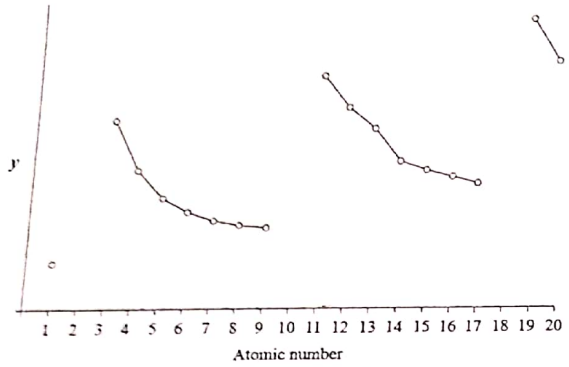
A. 4
B. 5
C. 7
D. 17

6. What would be observed when sodium is added to water?

I. A gas is evolved.
II. The pH of the solution increases.
III. The temperature of the water increases.

A. I and II only
B. I and III only
C. II and III only
D. I, II and III

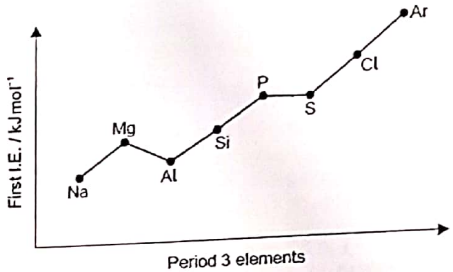
7. Which physical property of the elements is represented by y on the y-axis of the graph?



Source: International Baccalaureate Organization

A. Ionic radius
B. Atomic radius
C. Electronegativity
D. First ionization energy

8. Which statement explains the decrease in first ionization energies among the period 3 elements?



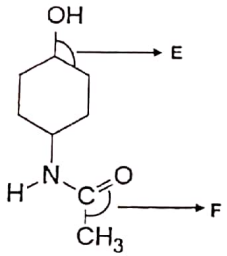
Source: International Baccalaureate Organization

	Between Mg and Al	Between P and S
A.	The p-orbital electron in Al is further from the nucleus than the s-orbital electron in Mg.	There is electron-electron repulsion in S but not in P.
B.	There is electron-electron repulsion in Al but not in Mg.	The p-orbital electron in P is further from the nucleus than the s-orbital electron in S.
C.	The effective nuclear charge in Al is higher than that of Mg.	There is less shielding effect by inner shell electrons in P compared to S.
D.	There is less shielding effect by inner shell electrons in Mg compared to Al.	The effective nuclear charge in S is higher than that of P.

9. Which compound is the most soluble in water?

A. $CH_3CH_2CH_3$
B. $F_3CCH_2CF_3$
C. $HCOOCH_2CH_3$
D $HOCH_2CH_2CH_2OH$

10. What are the values of angles **E** and **F** in the molecule?



	angle **E**	angle **F**
A.	120°	120°
B.	120°	109°
C.	109°	120°
D.	109°	109°

11. Which pair of molecules has the same molecular shape?

A. CO_2 and HCN
B. NH_3 and BH_3
C. NH_3 and H_2CO
D. BF_3 and PF_3

12. Which molecule is non-polar?

A. SF_2
B. NF_3
C. CF_4
D. CH_2F_2

13. Which molecule contains delocalized electrons?

A. Carbon dioxide, CO_2
B. Ozone, O_3
C. Methanoic acid, HCOOH
D. Propene, C_3H_6

14. The specific heat capacity of **X** is twice that of **Y**. In an experiment, the same amount of heat is supplied to 10 g of **X** and 5 g of **Y**.

What is the correct increase in temperature, in °C, for 10 g of **X** and 5 g of **Y**?

	10 g of **X**	5 g of **Y**
A.	5	10
B.	5	20
C.	10	10
D.	20	5

15. Which statement is correct for this reaction?

$2Mg\ (s) + CO_2\ (s) \rightarrow 2MgO\ (s) + C\ (s) \quad \Delta H = -780\ kJ$

A. 390 kJ of heat is absorbed for every mole of MgO produced.
B. 390 kJ of heat is released for every mole of MgO produced.
C. 780 kJ of heat is released for every mole of MgO produced.
D. 1560 kJ of heat is released for every mole of MgO produced.

16. The lattice enthalpy relates to the enthalpy change in the process:

$M_aX_b\ (s) \rightarrow aM^{b+}\ (g) + bX^{a-}\ (g)$

Which ionic compound has the most endothermic lattice enthalpy?

A. Lithium chloride
B. Potassium chloride
C. Potassium fluoride
D. Lithium fluoride

17. Which is true of the forward reaction of a non-spontaneous redox reaction?

A. The entropy change of the universe for the forward reaction is positive.
B. The Gibbs free energy change for the reverse reaction is positive.
C. The cell potential is negative.
D. The equilibrium constant is greater than one under standard conditions.

18. Why does increasing the temperature increases the rate of a chemical reaction?

A. More molecules have energy equal to or greater than the activation energy.
B. The activation energy for the reaction is lower at higher temperature.
C. The position of equilibrium shifts in the exothermic direction.
D. More molecules have the correct collision geometry.

19. Powdered manganese(IV) oxide, MnO_2, is added to increase the rate of the decomposition of aqueous hydrogen peroxide, H_2O_2. Which statements about MnO_2 are correct?

I. The rate does not depend on the particle size of MnO_2.
II. The mass of MnO_2 remains unchanged at the end of the decomposition.
III. MnO_2 provides an alternative reaction pathway for the decomposition with a lower activation energy.

A. I and II only
B. I and III only
C. II and III only
D. I, II and III

20. The overall chemical equation is shown below.

$Y_2 + Z \rightarrow YZ + Y$

The reaction occurs in two steps.

$Y_2 \rightarrow 2Y$ slow

$Y + Z \rightarrow YZ$ fast

What is the rate expression for this reaction?

A. Rate = k $[Y_2]$
B. Rate = k [2Y]
C. Rate = k [Y][Z]
D. Rate = k $[Y_2]$[Y][Z]

21. Hydrogen reacts with carbon dioxide as shown in the equation below.

$$H_2(g) + CO_2(g) \rightleftharpoons H_2O(g) + CO(g) \quad \Delta H = +41 \text{ kJ mol}^{-1}$$

The quantity of CO formed at equilibrium can be increased by

A. adding a suitable catalyst.
B. increasing the temperature.
C. removing $CO_2(g)$.
D. reducing the volume of the vessel.

22. Which statement is **incorrect** regarding a reversible reaction?

A. The system achieves equilibrium when the reaction quotient, Q, equals to the equilibrium constant, K_c.
B. Equilibrium is reached when the temperature of the system remains constant.
C. Equilibrium is reached when the concentrations of the reactants and products are constant.
D. Equilibrium is reached when the rate constant of forward reaction equals to the rate constant of the reverse reaction.

23. Which is true of the signs of $\Delta G^{\ominus}$ and $\Delta S^{\ominus}$ for a reaction that is spontaneous at all temperatures?

	$\Delta G^{\ominus}$	$\Delta S^{\ominus}$
A.	negative	negative
B.	positive	negative
C.	negative	positive
D.	positive	positive

24. The ionization of the HSO_3^- ion is shown below.

$$HSO_3^-(aq) + H_2O(l) \rightleftharpoons SO_3^{2-}(aq) + H_3O^+(aq)$$

Which are the Bronsted-Lowry acid and conjugate acid?

	Bronsted-Lowry acid	Conjugate acid
A.	HSO_3^-	SO_3^{2-}
B.	HSO_3^-	H_3O^+
C.	H_2O	SO_3^{2-}
D.	H_2O	H_3O^+

25. The pH of 1.0 mol dm^{-3} acid Q is 2.
Which statement can be deduced from this information?

A. Acid Q is a weak acid.
B. Acid Q is a dibasic acid.
C. Acid Q does not react with sodium carbonate.
D. The pH of acid Q decreases when it is diluted with water.

26. Which pair of solutions will produce a buffer solution when mixed in equal volumes? (The concentrations of all solutions are 1 mol dm^{-3}.)

A. H_2SO_4 and Na_2CO_3
B. CH_3COOH and NaOH
C. NaOH and CH_3COONa
D. NH_3 and NH_4Cl

27. Which of the **underlined** species is a Lewis acid?

I. $\underline{Al}Cl_4^-$

II. $[\underline{Cu}(H_2O)_6]^{2+}$

III. $\underline{N}H_4^+$

A. I and II only

B. I and III only

C. II and III only

D. I, II and III

28. Which is correct for the reaction below?

$Zn\ (s) + 2NaOH\ (aq) + 2H_2O\ (l) \rightarrow Na_2Zn(OH)_4\ (aq) + H_2\ (g)$

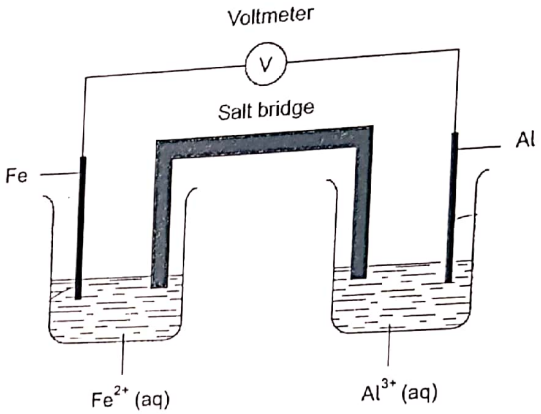
A. Zn is the oxidizing agent and the oxidation number of Zn increases.

B. Zn is the reducing agent and the oxidation number of Zn decreases.

C. Zn is the oxidizing agent and the oxidation number of H decreases.

D. Zn is the reducing agent and the oxidation number of H decreases.

29. A voltaic cell is constructed from aluminium and iron half-cells. Aluminium is more reactive than iron. Which statement is correct?



A. Negative ions flow through the salt bridge from the iron half-cell to the aluminium half-cell.

B. Electrons flow from the iron half-cell to the aluminium half-cell.

C. The concentration of Fe^{2+} (aq) increases.

D. Electrons flow through the salt bridge.

30. In the electrolysis of aqueous sodium sulfate, Na_2SO_4 (aq), using inert electrodes, 0.4 mol of a gas was formed at the anode (positive electrode).

Which is the correct observation made at the cathode (negative electrode)?

	Gas produced	Amount gas produced/ mol
A.	hydrogen	0.2
B.	oxygen	0.2
C.	hydrogen	0.8
D.	oxygen	0.8

31. What is the standard half-cell potential of nickel if the standard reference electrode is changed from the standard hydrogen electrode to a standard silver electrode?

	E° / V with respect to the standard hydrogen electrode
$Ag^+ (aq) + e^- \rightleftharpoons Ag (s)$	+0.80
$Ni^{2+} (aq) + 2e^- \rightleftharpoons Ni (s)$	−0.26

A. +1.06 V

B. −1.06 V

C. +0.54 V

D. −0.34 V

32. Which compound has the highest IHD value?

A. $CH_3CH_2CH_2CH_3$

B. $Cl_2C{=}CCl_2$

C. $CH_3CH_2NH_2$

D. HOOCCOOH

33. Which substances may be formed from the incomplete combustion of octane, C_8H_{18}?

I. C (soot)

II. CO

III. H_2

A. I and II only

B. I and III only

C. II and III only

D. I, II and III

34. Which is correct for benzene?

A. There are alternating single and double carbon-carbon bonds in the ring structure.

B. It readily undergoes addition reaction.

C. Its ^1H NMR spectrum shows only one signal.

D. Its ^1H NMR spectrum shows six signals.

35. Which statement is correct of the reaction between CH_3Cl and KCN?

A. An intermediate is formed during the reaction.

B. The reaction is slower if CH_3Cl is replaced by CH_3Br.

C. A protic, polar solvent should be used for this reaction.

D. The reaction occurs via a one-step mechanism.

36. Which molecules exhibit stereoisomerism?

I. 1,2-dichloroethene

II. 1,2-dibromocyclobutane

III. 1,2-difluoropropane

A. I and II only

B. I and III only

C. II and III only

D. I, II and III

37. The reaction pathway to produce pentan-3-one, $CH_3CH_2COCH_2CH_3$, from the alkene, C_5H_{10}, is shown below.

$$C_5H_{10} \xrightarrow[\text{Step 1}]{HBr} P \xrightarrow[\text{Step 2}]{NaOH} Q \xrightarrow[\text{Step 3}]{H^+/K_2Cr_2O_7} CH_3CH_2COCH_2CH_3$$

Which statement is **not** correct for this reaction pathway?

A. Pent-1-ene is used for this reaction.

B. Step 1 is an addition reaction.

C. Step 2 is a substitution reaction.

D. Acidified $K_2Cr_2O_7$ can be replaced by acidified $KMnO_4$ in Step 3.

38. Which compound will **not** react with lithium aluminium hydride, $LiAlH_4$?

A. CH_3CH_2COOH

B. CH_3COCH_3

C. CH_2CH_3CHO

D. $CH_3CH_2CH_2OH$

39. 50.0 ± 0.5 cm^3 of a liquid has a mass of 10.00 ± 0.01 g.

Which is the most appropriate expression for the density of the liquid?

A. 0.2000 g cm^{-3}

B. 0.200 g cm^{-3}

C. 0.20 g cm^{-3}

D. 0.2 g cm^{-3}

40. What information of a molecule **cannot** be obtained from single crystal X-ray crystallography analysis?

A. Bond lengths

B. Bond angles

C. Bond strength

D. Three-dimensional structure of the molecule

–End of Paper–

SCHOOL OF THE ARTS SINGAPORE

CHEMISTRY
Higher level
Paper 2
Preliminary Examinations

Tuesday 31 August 2022

2 hours 15 minutes

INSTRUCTIONS TO CANDIDATES

- *Write your name, class and index number in the blanks below.*
- *Do not open this examination paper until instructed to do so.*
- *Answer all questions.*
- *Answers must be written within the answer 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]***.

e: _____

: _____

_____

90

1. An organic compound contains the elements carbon, hydrogen and oxygen. Complete combustion of 0.6011 g of the organic compound produces 0.7208 g of water and 1.3203 g carbon dioxide.

(a) (i) Calculate the amount, in mol, of carbon present in the organic compound. [1]

.....

.....

(ii) Calculate the amount, in mol, of hydrogen present in the organic compound. [1]

.....

.....

(iii) Calculate the amount, in mol, of oxygen present in the organic compound. [1]

.....

.....

(iv) Determine the empirical formula of the organic compound. [1]

.....

.....

(b) 0.6011 g of the organic compound is found to contain 0.010 mol of the compound. Determine the molar mass of the organic compound. [1]

.....

.....

(c) Using your answer to parts (a)(iv) and (b), determine the molecular formula of the organic compound. [1]

2. (a) Describe the acid-base character of the oxides of the period 3 elements, Na to Cl. [1]

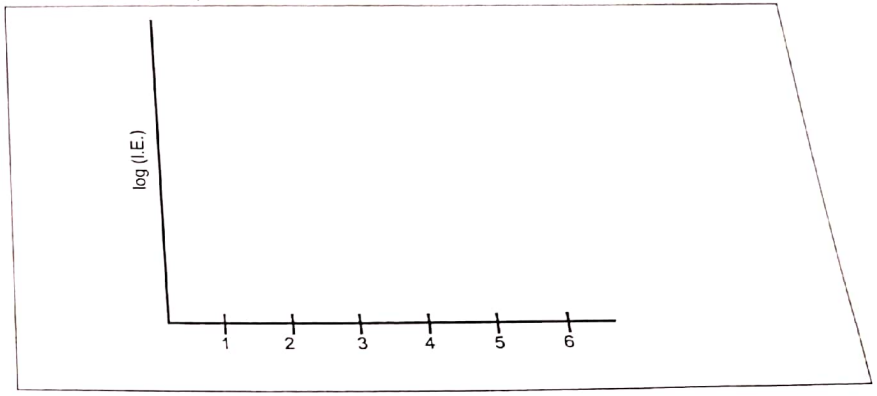
(b) Formulate an equation for the reaction of phosphorus(V) oxide, P_4O_{10}, with water. [1]

(c) Vanadium has two common natural isotopes; vanadium-50 and vanadium-51. The mass spectrum of a sample of vanadium gave the following data:

Mass number	% abundance
50	0.250
51	99.750

Suggest a reason for the low percentage abundance of vanadium-50. [1]

(d) Sketch a graph of the first six successive ionization energies (I.E.) of vanadium on the axes provided. [2]



(e) Explain why aqueous $[V(H_2O)_6]^{2+}$ is violet using section 17 of the data booklet. [3]

(f) *Vanadium trifluoride reacts with liquid ammonia to form* $VF_3(NH_3)_3$.

(i) Deduce the oxidation state of vanadium in $VF_3(NH_3)_3$. [1]

.....

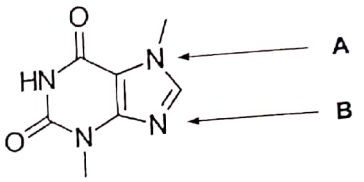
.....

(ii) Explain the magnetic property of $VF_3(NH_3)_3$. [1]

.....

.....

3. Theobromine is found in chocolate. The skeletal representation of theobromine is shown below.



(a) (i) List the number of pi (π) bonds in theobromine. [1]

.....

(ii) Sketch the shape of one sigma (σ) and one pi (π) bond. [2]

sigma (σ) bond:

pi (π) bond:

(iii) Deduce the hybridisation of the nitrogen atoms labelled **A** and **B**. [2]

A:..... **B:** .....

(b) The chemical formula for the carbonate ion is CO_3^{2-}.

(i) Draw the Lewis structure of CO_3^{2-}. [1]

(ii) Explain the molecular geometry of CO_3^{2-}. [2]

(iii) Comment on the bond length of the carbon-oxygen bond in CO_3^{2-}. [2]

4. Solid nitrogen triiodide, NI_3, is a type of contact explosive. It explodes easily when touched.

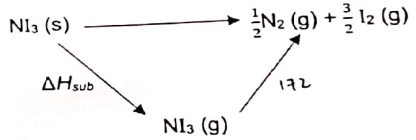
(a) (i) Calculate the enthalpy change of reaction, ΔH, in kJ, when 1.00 mol of gaseous NI_3 decompose into its elements. Use section 11 of the data booklet and the N-I bond enthalpy of 159 kJ mol^{-1}. [3]

$$NI_3\,(g) \rightarrow \tfrac{1}{2}N_2\,(g) + \tfrac{3}{2}I_2\,(g)$$

(ii) The enthalpy change for the explosion of solid NI_3 is −145 kJ mol^{-1}.

$$NI_3\,(s) \rightarrow \tfrac{1}{2}N_2\,(g) + \tfrac{3}{2}I_2\,(g) \qquad \Delta H = -145 \text{ kJ mol}^{-1}$$

Using your answer from part (a) and the energy cycle below, calculate the enthalpy change of sublimation, ΔH_{sub}, of NI_3 in kJ mol^{-1}.



(If you did not get an answer to part (a), use -85 kJ mol^{-1} but this is not the correct answer.) [2]

(b) Nitrogen trifluoride, NF_3, has a structure similar to NI_3.

(i) Calculate the standard enthalpy change, $\Delta H^{\ominus}$, in kJ mol^{-1}, for the decomposition of NF_3.

$$NF_3\,(g) \rightarrow \tfrac{1}{2}N_2\,(g) + 3F\,(g)$$ [1]

	Enthalpy change of formation $\Delta H_f^{\ominus}$ / kJ mol^{-1}
NF_3 (g)	−132.1
F (g)	+79.4

(ii) Calculate the entropy change, $\Delta S^{\ominus}$, for this reaction. [1]

	Entropy, $S^{\ominus}$ / J K^{-1} mol^{-1}
F (g)	158.8
N_2 (g)	191.6
NF_3 (g)	260.8

(iii) Using your answers from (b)(i) and (ii), and section 1 of the data booklet, comment if this reaction is spontaneous at 25 °C.

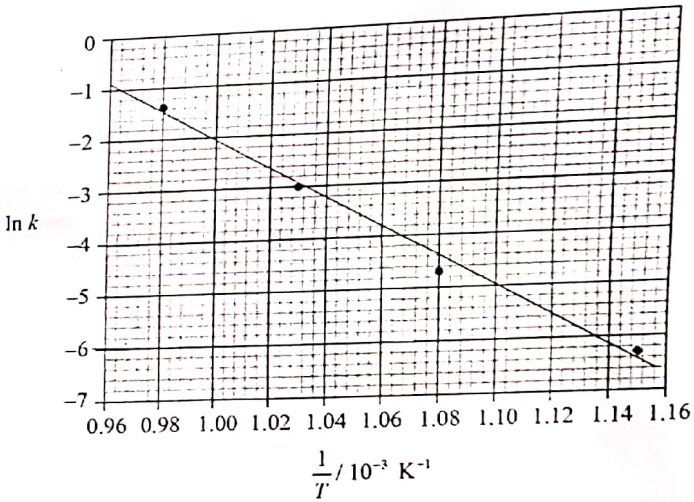
(If you did not obtain an answer in (b)(i) or (b)(ii), use −87.6 kJ mol^{-1} and −150.5 J K^{-1} mol^{-1} respectively, but these are not the correct answers.) [2]

5. The Arrhenius equation, $k = Ae^{-\frac{E_a}{RT}}$, shows the relationship between rate constant and temperature, T (in Kelvin). [1]

(a) State how temperature affects activation energy.

(b) The graph of ln k against $\frac{1}{T}$ for the decomposition of N_2O is shown below.

$$N_2O \rightarrow N_2 + O$$



Source: International Baccalaureate Organization

(i) State how the rate constant, k, varies with temperature, T. [1]

(ii) Determine the activation energy, E_a, for this reaction, using section 1 and 2 of the data booklet. [3]

(c) The rate expression for this reaction is rate = k $[N_2O]^2$. The value of the rate constant at 1023 K is 0.244.

(i) Deduce the units of the rate constant. [1]

(ii) A sample of N_2O of concentration 0.500 mol dm^{-3} is decomposed at 1023 K. Calculate the rate when 20% of the N_2O has reacted. [2]

(iii) Predict the effect of a catalyst on the value of the rate constant. [1]

6. Methane reacts with steam as shown in the equation below.

$$CH_4(g) + H_2O(g) \rightleftharpoons CO(g) + 3H_2(g) \quad \Delta H = +131 \text{ kJ mol}^{-1}$$

(a) State the equilibrium constant expression, K_c, for the reaction above. [1]

(b) Explain how the position of equilibrium would be affected by decreasing the volume of the reaction container at constant temperature. [1]

(c) CH_4 (2.00 mol dm^{-3}) and H_2O (1.00 mol dm^{-3}) are mixed and allowed to reach equilibrium at 450 K.

	CH_4	H_2O	CO	H_2
Initial concentration / mol dm^{-3}	2.00	1.00	0.00	0.00
Equilibrium concentration / mol dm^{-3}	.....	0.30	.....	.....

(i) Deduce the equilibrium concentrations of CH_4, CO and H_2 in the table above. [2]

(ii) Calculate the value of K_c at 450 K. [1]

(iii) Predict the value of Gibb's free energy change, ΔG, of the equilibrium mixture at 450 K. [1]

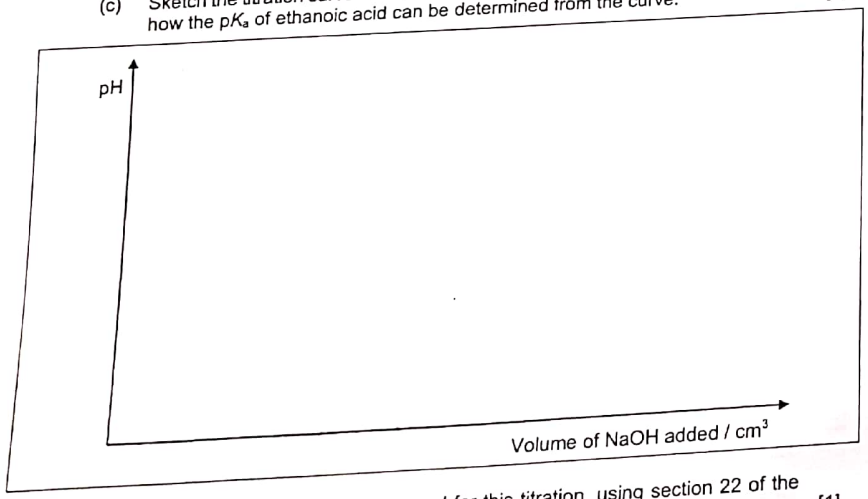
7. 25.0 cm^3 of aqueous ethanoic acid is titrated against aqueous sodium hydroxide (0.100 mol dm^{-3}). 27.60 cm^3 of aqueous sodium hydroxide is required to completely neutralize the acid.

$$NaOH\ (aq) + CH_3COOH\ (aq) \rightarrow CH_3COONa\ (aq) + H_2O\ (l)$$

(a) Calculate the concentration of ethanoic acid. [1]

(b) Calculate the pH of the aqueous sodium hydroxide at 298 K. [2]

(c) Sketch the titration curve of ethanoic acid with aqueous sodium hydroxide. Show how the pK_a of ethanoic acid can be determined from the curve. [3]



(d) Suggest an indicator that can be used for this titration, using section 22 of the data booklet. [1]

Turn over

8. Pure aluminium is obtained by electrolysis of molten aluminium oxide, Al_2O_3, between 940 °C to 980 °C.

(a) Deduce the half-equations for the reactions at each electrode. [2]

Anode (positive electrode) :

Cathode (negative electrode) :

(b) Deduce the overall cell reaction including the state symbols, using section 7 of the data booklet. [2]

(c) 80 kg of aluminium is produced when a current, I, is passed through the electrolyte for 2 hours. Predict the mass of aluminium, in kg, that will be produced if a current, $2I$, is passed through the electrolyte for 3 hours. [1]

(d) Pure aluminium is used in the aluminium-hydrogen peroxide fuel cell. The reaction for the fuel cell is shown below.

$2Al\ (s) + 3H_2O_2\ (aq) + 6H^+\ (aq) \rightarrow 2Al^{3+}\ (aq) + 6H_2O\ (l)$ $E^{\ominus}_{cell} = +3.44\ V$

In this fuel cell, aluminium is oxidized to aluminium ion, $Al\ (s) \rightarrow Al^{3+}\ (aq) + 3e^-$

(i) Calculate the standard Gibbs free energy, $\Delta G^{\ominus}$, in kJ mol^{-1}, of this reaction, using section 1 of the data booklet. [2]

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.....

.....

(ii) Formulate the half-equation for the reduction of hydrogen peroxide. [1]

.....

.....

(iii) Calculate the standard electrode potential for the reduction of hydrogen peroxide using section 24 of the data booklet. [1]

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9. Cyclohexane and (Z)-hex-3-ene are isomers with the molecular formula C_6H_{12}. Both are colourless liquids at room temperature.

(a) Draw the structural formula of (Z)-hex-3-ene. [1]

(b) Describe a chemical test and the expected result that distinguishes cyclohexane and (Z)-hex-3-ene. [2]

Test:

.....

Result:

.....

.....

.....

(c) Three signals were observed in the high resolution ^1H NMR spectrum of (Z)-hex-3-ene.

(i) Predict the ratio of the integration trace and the splitting pattern of the three signals using section 27 of the data booklet. [3]

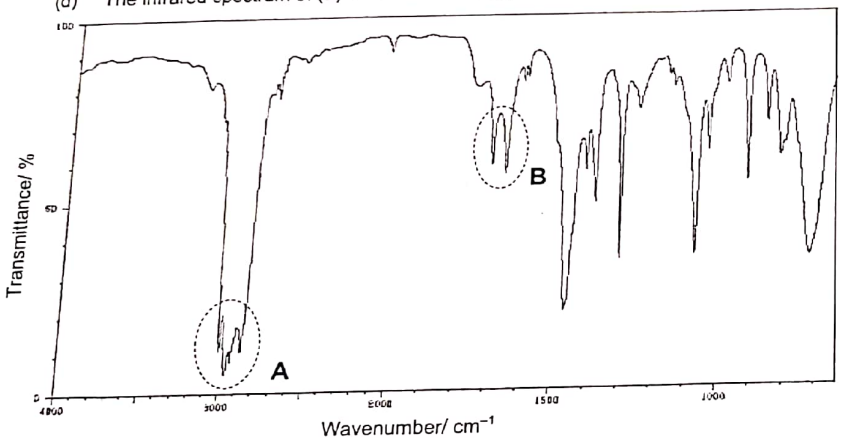
Chemical shift /ppm	Ratio of integration trace	Splitting pattern
0.96	.....	.....
2.03	.....	.....
5.33	.....	.....

(ii) Outline how the ^{1}H NMR spectrum of cyclohexane is different from that of (Z)-hex-3-ene. [1]

.....

.....

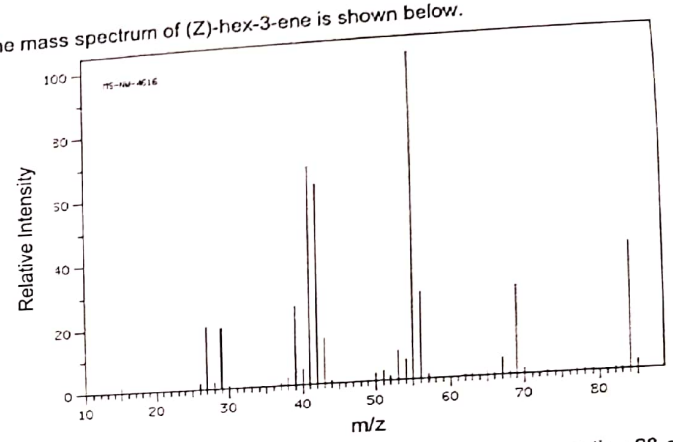
(d) The infrared spectrum of (Z)-hex-3-ene is shown below.



Identify the bonds responsible for the absorptions at **A** and **B** in the infrared spectrum using section 26 of the data booklet. [2]

A: ..... **B**: .....

(e) The mass spectrum of (Z)-hex-3-ene is shown below.



Suggest the fragments that cause the following peaks using section 28 of the data booklet.. [2]

m/z 27: ..... *m/z* 69: .....

(f) (Z)-hex-3-ene reacts with hydrogen bromide to form 3-bromohexane.

(i) Sketch the mechanism of the reaction between (Z)-hex-3-ene and hydrogen bromide, using curly arrows to represent movement of electron pairs. [4]

(ii) Suggest a reason why the product obtained for this reaction does **not** rotate plane-polarized light. [1]

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(g) A mixture of cyclohexane, C_6H_{12}, (in large excess) and chlorine is exposed to UV radiation to start a chemical reaction. A monochlorinated product, $C_6H_{11}Cl$, is formed as the major product at the end of the reaction.

(i) State the mechanism of the reaction between cyclohexane and chlorine. [1]

.....

(ii) Suggest a reason why cyclohexane is used in large excess. [1]

.....

.....

(iii) The mechanism of this reaction involves three stages: initiation, propagation and termination. List the **two** chemical equations in the propagation stage to form $C_6H_{11}Cl$. [2]

.....

.....

.....

(iv) State the formula of the hydrocarbon compound formed in the termination stage. [1]

.....

.....

Turn over

The monochlorinated product, $C_6H_{11}Cl$, is further reacted in the two-step reaction pathway as shown.

$$C_6H_{11}Cl \xrightarrow[\text{Step 1}]{NaOH(aq)} C_6H_{11}OH \xrightarrow[\text{Step 2}]{\text{conc. } H_2SO_4} CH_3COOC_6H_{11}$$

(v) Deduce the type of reaction in Step 1. [1]

.....

(vi) $C_6H_{11}OH$ is reacted with another organic compound in the presence of a small amount of concentrated sulfuric acid in Step 2. Deduce the organic compound used. [1]

.....

(vii) Outline the purpose of adding concentrated sulfuric acid in Step 2. [1]

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Source: All spectral diagrams are extracted from https://www.aist.go.jp

-End of Paper-