

Please check the examination details below before entering your candidate information

|                                                                                                       |                 |                      |                      |
|-------------------------------------------------------------------------------------------------------|-----------------|----------------------|----------------------|
| Candidate surname                                                                                     |                 | Other names          |                      |
| <b>Pearson Edexcel</b>                                                                                |                 | Centre Number        | Candidate Number     |
| <b>Level 3 GCE</b>                                                                                    |                 | <input type="text"/> | <input type="text"/> |
| Time 1 hour 30 minutes                                                                                | Paper reference | <b>8CH0/02</b>       |                      |
| <b>Chemistry</b><br><b>Advanced Subsidiary</b><br><b>PAPER 2: Core Organic and Physical Chemistry</b> |                 |                      |                      |
| Candidates must have: <b>Scientific calculator</b><br><b>Data Booklet</b><br><b>Ruler</b>             |                 |                      | Total Marks          |

### Instructions

- Use **black** ink or **black** ball-point pen.
- **Fill in the boxes** at the top of this page with your name, centre number and candidate number.
- Answer **all** questions.
- Answer the questions in the spaces provided  
– *there may be more space than you need.*

### Information

- The total mark for this paper is 80.
- The marks for **each** question are shown in brackets  
– *use this as a guide as to how much time to spend on each question.*
- For the question marked with an **asterisk** (\*), marks will be awarded for your ability to structure your answer logically, showing the points that you make are related or follow on from each other where appropriate.
- A Periodic Table is printed on the back cover of this paper.

### Advice

- Read each question carefully before you start to answer it.
- Show all your working in calculations and include units where appropriate.
- Check your answers if you have time at the end.
- Good luck with your examination.

Turn over ►

P67084A

©2021 Pearson Education Ltd.

1/1/1/1/



Pearson

DO NOT WRITE IN THIS AREA

DO NOT WRITE IN THIS AREA

DO NOT WRITE IN THIS AREA

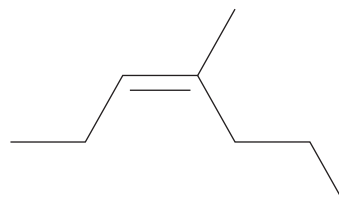
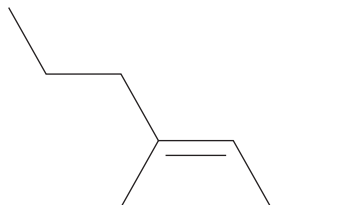
**BLANK PAGE**



Answer ALL questions.

Some questions must be answered with a cross in a box ☐. If you change your mind about an answer, put a line through the box ☒ and then mark your new answer with a cross ☐.

- 1 The structures of two isomers are shown.



What kind of isomerism is shown by these molecules?

- ☐ A carbon chain
- ☐ B positional
- ☐ C *E/Z*
- ☐ D *cis/trans*

(Total for Question 1 = 1 mark)



- 2 Phosphorus(V) chloride,  $\text{PCl}_5$ , can be thermally decomposed to phosphorus(III) chloride,  $\text{PCl}_3$ , and chlorine,  $\text{Cl}_2$ . The equation for this reaction is



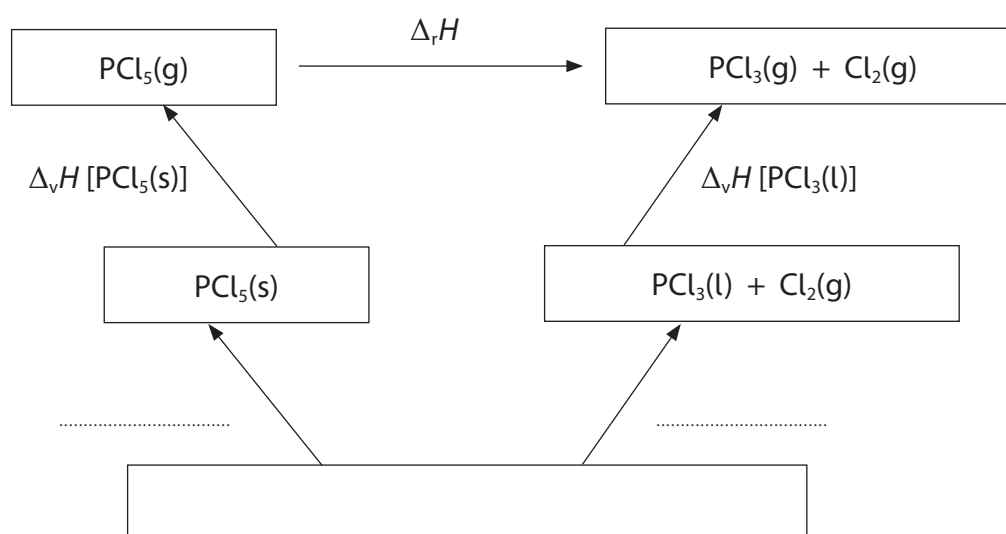
The enthalpy change for this reaction cannot be measured directly.

- (a) (i) Complete the Hess's Law cycle to include the enthalpy change of formation of both phosphorus chlorides.

Include the labels of the missing enthalpy changes.

$\Delta_v H$  is the enthalpy change for the vaporisation of the substance from the state shown to the gaseous state.

(3)

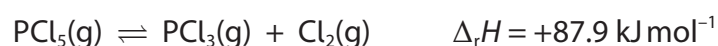


- (ii) Calculate the enthalpy change for the thermal decomposition of  $\text{PCl}_5(\text{g})$  to  $\text{PCl}_3(\text{g})$  and  $\text{Cl}_2(\text{g})$ , using the data given in the table. Include a sign and units in your answer.

(2)

|                                       | Enthalpy change / $\text{kJ mol}^{-1}$ |
|---------------------------------------|----------------------------------------|
| $\Delta_f H [\text{PCl}_5(\text{s})]$ | -443.5                                 |
| $\Delta_f H [\text{PCl}_3(\text{l})]$ | -319.7                                 |
| $\Delta_v H [\text{PCl}_5(\text{s})]$ | +64.9                                  |
| $\Delta_v H [\text{PCl}_3(\text{l})]$ | +30.5                                  |

- (b) Another source gave a different value for the enthalpy change of this reaction.



Explain the effect, if any, of increasing the temperature on the position of the equilibrium at constant volume.

(2)

.....

.....

.....

.....

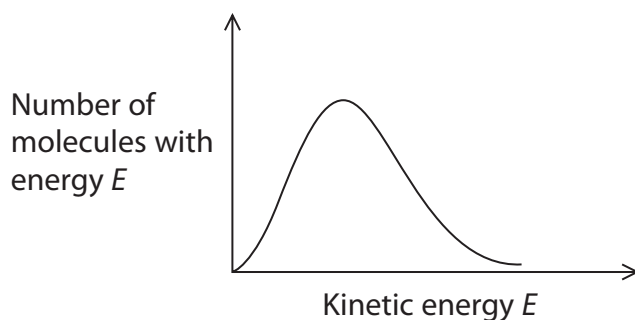
.....

.....

(Total for Question 2 = 7 marks)

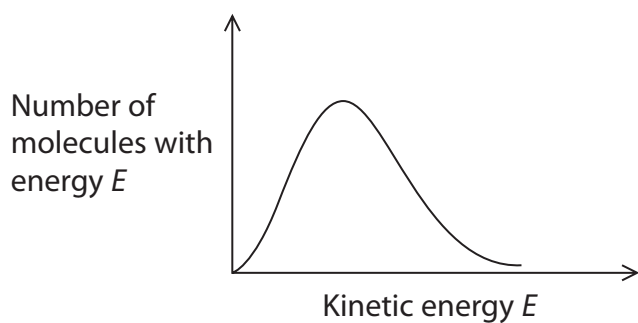


- 3 The Maxwell-Boltzmann distribution of molecular energies for the reactant molecules in an uncatalysed reaction is shown.

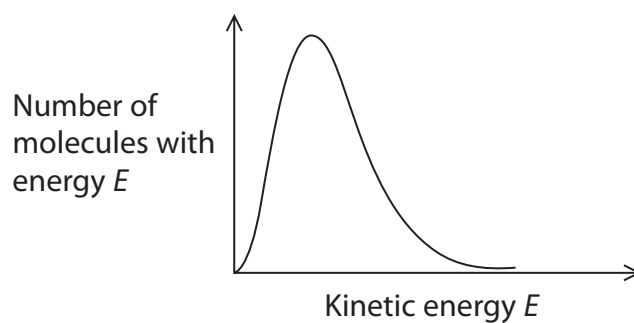


Which of these Maxwell-Boltzmann distributions would you expect for the same molecules in the presence of a catalyst at the same temperature and pressure?  
All diagrams are drawn to the same scale.

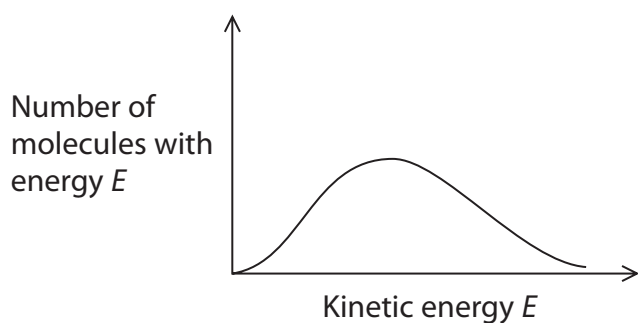
☐ A



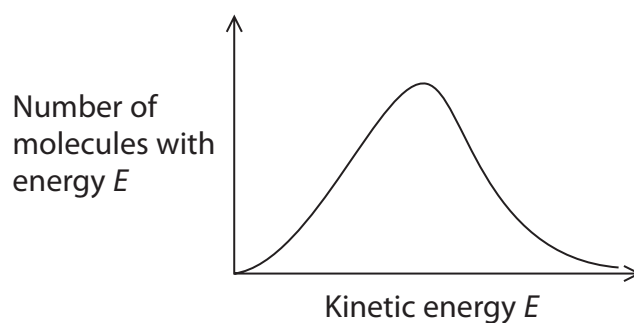
☐ B



☐ C



☐ D



(Total for Question 3 = 1 mark)



DO NOT WRITE IN THIS AREA

DO NOT WRITE IN THIS AREA

DO NOT WRITE IN THIS AREA

**BLANK PAGE**



- 4 When solid calcium sulfate dihydrate,  $\text{CaSO}_4 \cdot 2\text{H}_2\text{O}$ , is heated in a crucible, it forms solid calcium sulfate hemihydrate,  $\text{CaSO}_4 \cdot \frac{1}{2}\text{H}_2\text{O}$ .

(a) Write an equation, including state symbols, for this reaction.

(1)

(b) Which two terms could be used to describe this reaction?

(1)

|                            | Enthalpy change | Type of process |
|----------------------------|-----------------|-----------------|
| <input type="checkbox"/> A | endothermic     | hydration       |
| <input type="checkbox"/> B | exothermic      | hydration       |
| <input type="checkbox"/> C | exothermic      | dehydration     |
| <input type="checkbox"/> D | endothermic     | dehydration     |

(c) When water is added to calcium sulfate hemihydrate, there is a rise in temperature.

A student decided to investigate this reaction using the following procedure:

**Step 1** 10 cm<sup>3</sup> of distilled water is measured using a measuring cylinder having an uncertainty of  $\pm 0.5 \text{ cm}^3$ , and is placed in an insulated cup with a lid.

**Step 2** A thermometer with an uncertainty of  $\pm 0.5^\circ\text{C}$  is placed in the water.

**Step 3** Exactly 10.00 g of calcium sulfate hemihydrate is weighed out using a balance with an uncertainty of  $\pm 0.005 \text{ g}$ .

**Step 4** The weighed quantity of calcium sulfate hemihydrate is added to the water in the insulated cup.

**Step 5** The mixture in the insulated cup is stirred until no further temperature change is observed.

### Results

Temperature of the water before adding the solid =  $23.5^\circ\text{C}$

Maximum temperature of the mixture after adding the solid =  $26.3^\circ\text{C}$

### Other data

Molar mass of calcium sulfate hemihydrate,  $\text{CaSO}_4 \cdot \frac{1}{2}\text{H}_2\text{O}$  =  $145.2 \text{ g mol}^{-1}$

Density of water =  $1.00 \text{ g cm}^{-3}$



- (i) Calculate the minimum volume of water needed to convert 10.00 g of  $\text{CaSO}_4 \cdot \frac{1}{2}\text{H}_2\text{O}$  into  $\text{CaSO}_4 \cdot 2\text{H}_2\text{O}$ .

(2)

- (ii) Calculate the enthalpy change, in  $\text{kJ mol}^{-1}$ , for this reaction.  
Include a sign in your answer and give your answer to an appropriate number of significant figures.

Assume that the liquid has a mass of 10.00 g and a specific heat capacity of  $4.18 \text{ J g}^{-1} \text{ }^\circ\text{C}^{-1}$ .

(4)

- (iii) Deduce which measurement has the greatest uncertainty in this experiment.  
Justify your answer by calculating the percentage uncertainty of this piece of apparatus.

(2)

(Total for Question 4 = 10 marks)



P 6 7 0 8 4 A 0 9 2 8

5 This question concerns the combustion of fossil fuels in power stations.

(a) One type of power station uses the combustion of methane gas to generate power.

Write an equation for the incomplete combustion of methane gas to form carbon monoxide and water only. State symbols are not required.

(2)

(b) One of the problems associated with the combustion of some fossil fuels is the production of acidic gases, including the oxides of nitrogen and sulfur.

(i) Explain how oxides of sulfur and nitrogen can be formed from the combustion of fossil fuels.

(2)

.....

.....

.....

.....

.....

.....

DO NOT WRITE IN THIS AREA

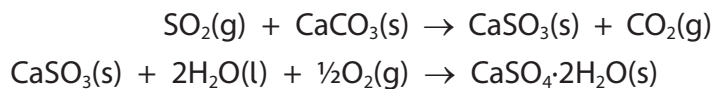
DO NOT WRITE IN THIS AREA

DO NOT WRITE IN THIS AREA



- (ii) Some power stations use a process of flue gas desulfurisation (FGD) to remove sulfur oxides from the gaseous combustion products.  
One such process, known as wet scrubbing, uses a mixture of calcium carbonate and water to react with sulfur dioxide.

Two relevant equations are



Explain why this process is an incomplete solution to the problem of burning fossil fuels.

Use the equations provided to illustrate your answer.

(2)

.....

.....

.....

.....

.....

.....

- (c) Draw a dot-and-cross diagram for sulfur dioxide, showing outer electrons only.

(1)

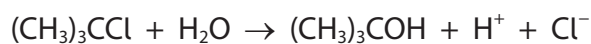
(Total for Question 5 = 7 marks)



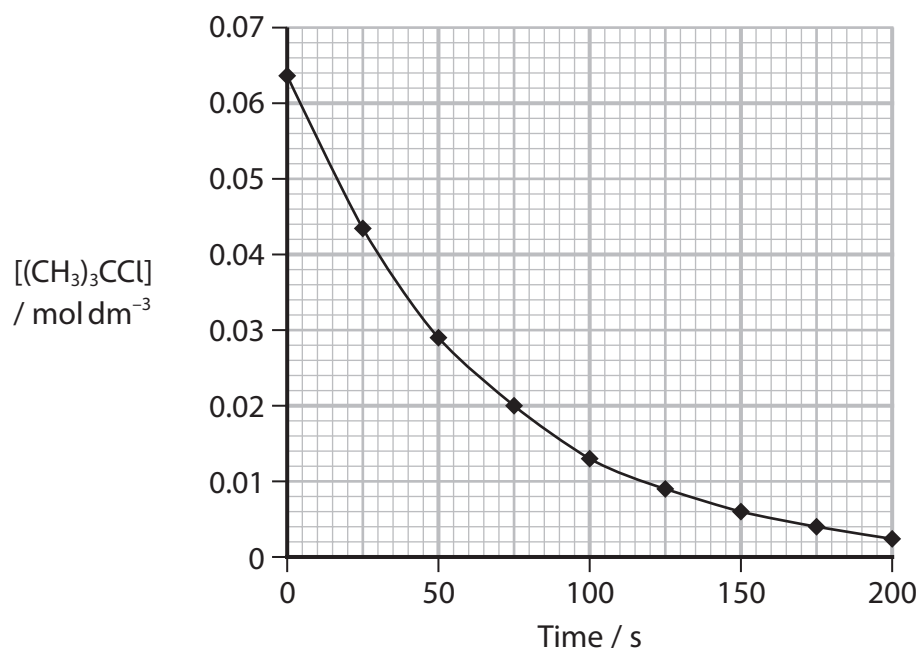
6 This question is about halogenoalkanes.

2-chloro-2-methylpropane can be hydrolysed by water.

The equation for this reaction is



The graph shows how the concentration of 2-chloro-2-methylpropane changes with time during an investigation of this reaction.



- (a) Calculate the rate of reaction at 50 s. Show your working on the graph. Include units with your final answer.

(3)

Rate of reaction at 50 s = .....

- (b) What is the classification of the mechanism for the hydrolysis of 2-chloro-2-methylpropane by water?

(1)

- ☐ **A** addition
- ☐ **B** elimination
- ☐ **C** free radical substitution
- ☐ **D** nucleophilic substitution



(c) The letters X, Y and Z refer to three different halogenoalkanes:

|   |                         |
|---|-------------------------|
| X | 1-bromobutane           |
| Y | 2-bromobutane           |
| Z | 2-bromo-2-methylpropane |

1 cm<sup>3</sup> of each of these halogenoalkanes was added to separate test tubes containing 5 cm<sup>3</sup> of ethanol and 5 cm<sup>3</sup> of aqueous silver nitrate solution in a water bath at 50 °C.

- (i) State the visible change in the reaction of an ethanol/silver nitrate solution with halogenoalkane X.

Include the **formula** of the compound responsible for this observation.

(2)

- (ii) The three halogenoalkanes were placed in order of **decreasing** rate of reaction. Which is the correct sequence?

(1)

- ☐ **A** X, Z, Y
- ☐ **B** Z, X, Y
- ☐ **C** Z, Y, X
- ☐ **D** X, Y, Z



(d) Under different conditions, 2-chloro-2-methylpropane can react to produce 2-methylpropene,  $(\text{CH}_3)_2\text{C}=\text{CH}_2$ .

(i) State the reagent and conditions needed for this reaction.

(2)

(ii) Draw the displayed formula for the repeat unit of a polymer that is made by the polymerisation of 2-methylpropene,  $(\text{CH}_3)_2\text{C}=\text{CH}_2$ .

(1)

(iii) Draw a mechanism for the addition of hydrogen bromide, HBr, to 2-methylpropene to form 2-bromo-2-methylpropane.  
Include curly arrows, and any relevant dipoles and lone pairs.

(4)

(Total for Question 6 = 14 marks)



- 7** This question is about the solubility of some alcohols.  
The table shows the solubility in water of the first six alcohols in a homologous series.

| Alcohol     | Solubility / g dm <sup>-3</sup> |
|-------------|---------------------------------|
| methanol    | soluble in all proportions      |
| ethanol     | soluble in all proportions      |
| propan-1-ol | soluble in all proportions      |
| butan-1-ol  | 632                             |
| pentan-1-ol | 22                              |
| hexan-1-ol  | 5.9                             |

- (a) State what is meant by a homologous series.

You may use the alcohols in the table to illustrate your answer.

(1)

.....

.....

.....

- (b) Explain why methanol and water are 'soluble in all proportions'.

You must include a diagram in your answer.

(3)

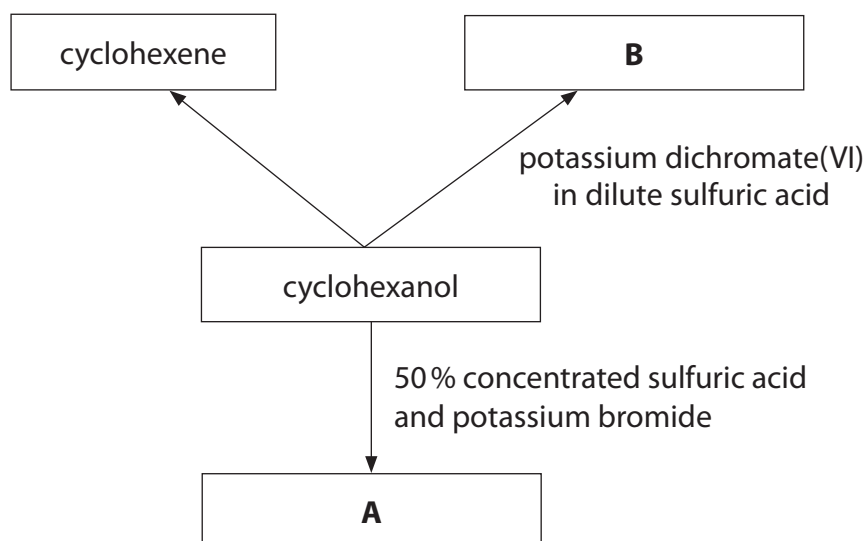
.....

.....

**(Total for Question 7 = 4 marks)**



8 This question is about some reactions of cyclohexanol.



DO NOT WRITE IN THIS AREA

DO NOT WRITE IN THIS AREA

DO NOT WRITE IN THIS AREA

(a) Write the **skeletal** formula of compound **A**.

(1)

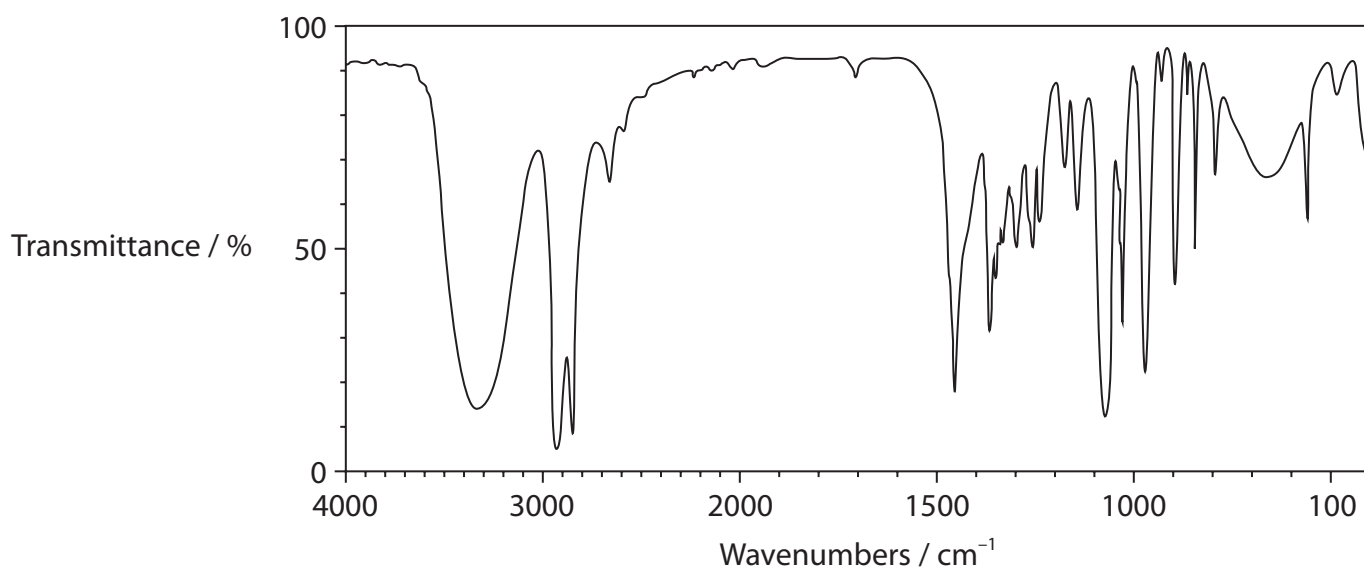
(b) (i) Give the name **and** displayed formula of compound **B**.

(2)

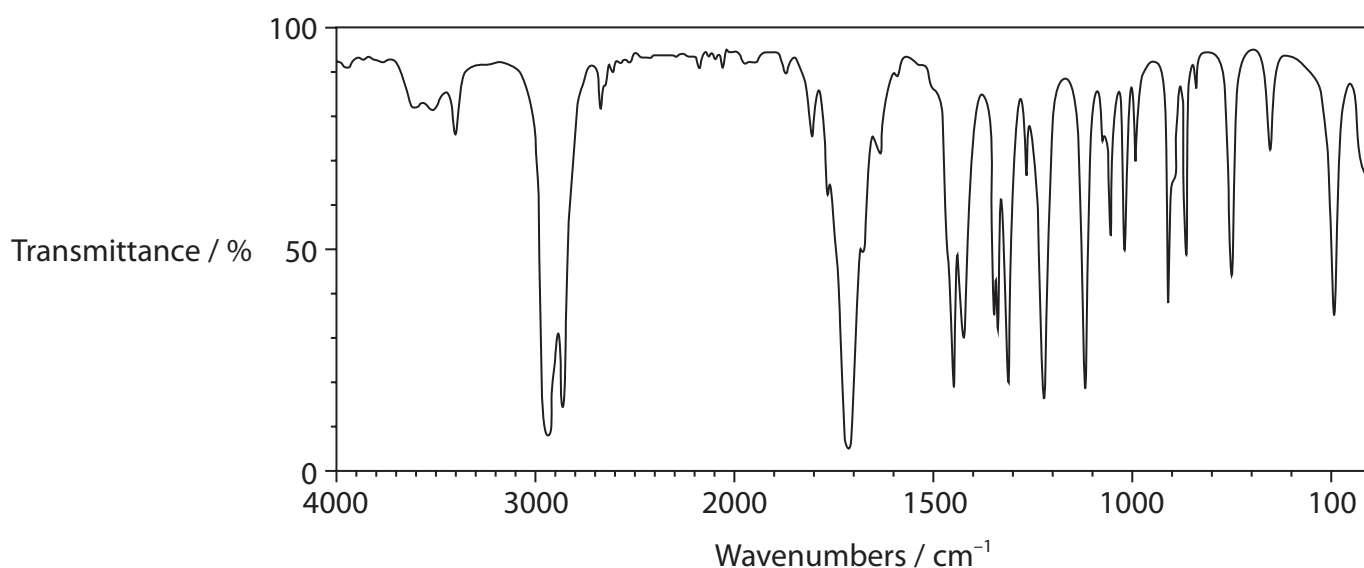


(ii) The infrared (IR) spectra of cyclohexanol and compound **B** are shown.

IR Spectrum of cyclohexanol



IR Spectrum of compound **B**



Identify the bonds, using **both** IR spectra, that help to confirm the reaction of cyclohexanol to produce compound **B**.

Your answer must include the wavenumber ranges of any relevant bonds.

(2)

.....

.....

.....

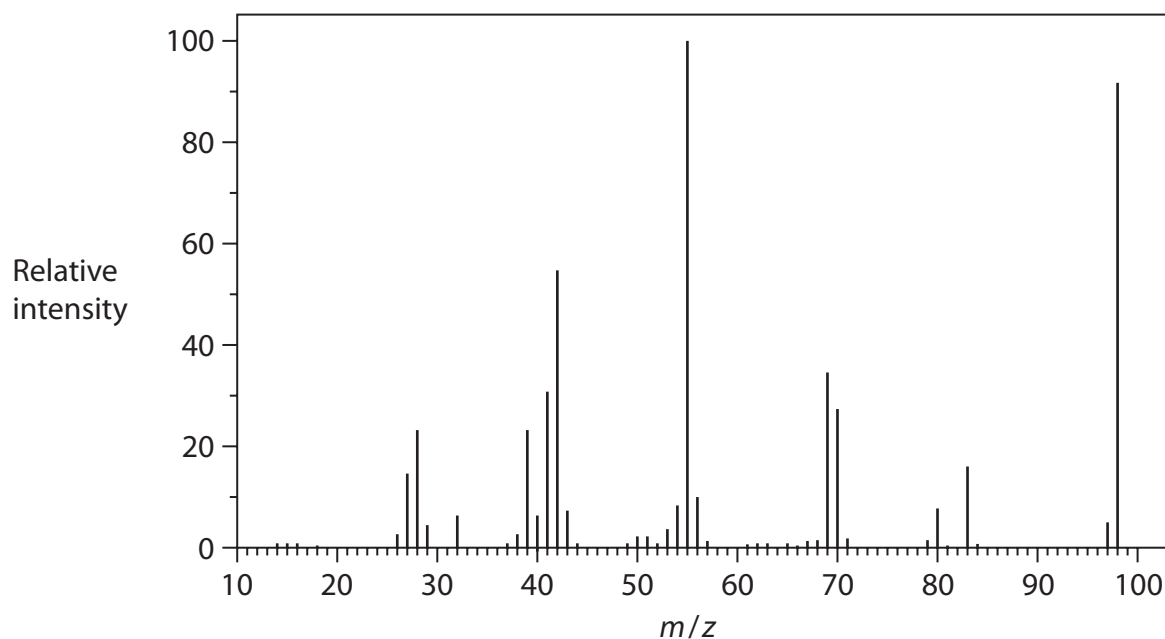
.....

.....

.....



(iii) The mass spectrum of compound **B** is shown.



Deduce the relative molecular mass of compound **B** using the mass spectrum.  
Justify your answer.

(1)

(iv) In the mass spectrum of cyclohexanol, there is a peak at  $m/z = 83$ .

Give the formula of a fragment that could be responsible for this peak.

(2)



DO NOT WRITE IN THIS AREA

DO NOT WRITE IN THIS AREA

DO NOT WRITE IN THIS AREA

- (c) (i) Cyclohexanol can be converted to cyclohexene.  
What is the classification for this reaction?

(1)

- ☐ **A** addition
- ☐ **B** elimination
- ☐ **C** oxidation
- ☐ **D** substitution

- (ii) In an experiment,  $10.0 \text{ cm}^3$  of cyclohexanol was converted to cyclohexene with a 63.0% yield.

| Compound     | Molar mass / $\text{g mol}^{-1}$ | Density / $\text{g cm}^{-3}$ |
|--------------|----------------------------------|------------------------------|
| cyclohexanol | 100                              | 0.962                        |
| cyclohexene  | 82.0                             | 0.811                        |

Calculate the volume of cyclohexene produced.

(4)



- \*(iii) Cyclohexene can be prepared by reacting cyclohexanol with phosphoric(V) acid. The mixture is warmed in a water bath for 15 minutes before distilling off a mixture of cyclohexene and water.

Devise a procedure to obtain a pure, dry sample of cyclohexene from the distillate. Include a reason for each step.

[Boiling temperature of cyclohexene =  $83^{\circ}\text{C}$

Density of cyclohexene =  $0.811\text{ g cm}^{-3}$ ]

(6)

DO NOT WRITE IN THIS AREA

DO NOT WRITE IN THIS AREA

DO NOT WRITE IN THIS AREA



DO NOT WRITE IN THIS AREA

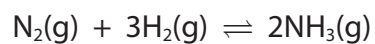
DO NOT WRITE IN THIS AREA

DO NOT WRITE IN THIS AREA

**(Total for Question 8 = 19 marks)**

P 6 7 0 8 4 A 0 2 1 2 8

- 9 An equation for the formation of ammonia using the Haber process is shown.



- (a) (i) Calculate the enthalpy change for the forward reaction shown in the equation, selecting from the bond enthalpies in the table.  
Include a sign in your answer.

(3)

| Bond | Mean bond enthalpy / $\text{kJ mol}^{-1}$ |
|------|-------------------------------------------|
| N—N  | 158                                       |
| N=N  | 410                                       |
| N≡N  | 945                                       |
| N—H  | 391                                       |
| H—H  | 436                                       |

DO NOT WRITE IN THIS AREA

DO NOT WRITE IN THIS AREA

DO NOT WRITE IN THIS AREA



- (ii) A data book gives the standard enthalpy change of formation of ammonia as  $-46.1 \text{ kJ mol}^{-1}$ .

Give two reasons for the difference between this value and the value that you calculated in (a)(i).

(2)

Reason 1

.....

.....

.....

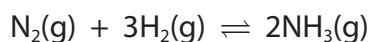
Reason 2

.....

.....

.....

- (iii) What is the percentage atom economy, by mass, for ammonia in the forward reaction?



(1)

- ☐ **A** 17.6 %
- ☐ **B** 50.0 %
- ☐ **C** 82.4 %
- ☐ **D** 100 %

- (iv) What is the equilibrium expression for  $K_c$ ?

(1)

- ☐ **A**  $K_c = \frac{[\text{N}_2][3\text{H}_2]}{[2\text{NH}_3]}$
- ☐ **B**  $K_c = \frac{[2\text{NH}_3]}{[\text{N}_2][3\text{H}_2]}$
- ☐ **C**  $K_c = \frac{[\text{NH}_3]^2}{[\text{N}_2][\text{H}_2]^3}$
- ☐ **D**  $K_c = \frac{[\text{N}_2][\text{H}_2]^3}{[\text{NH}_3]^2}$



(b) In the chemical industry, many processes involve reversible reactions. The product is often removed before equilibrium is attained.

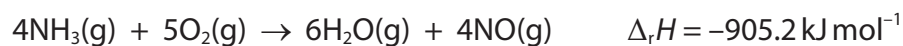
Give three reasons why the product may be removed before its maximum concentration is achieved.

(3)



(c) Ammonia is stable in air but can be oxidised on the surface of a copper catalyst.

An equation for this reaction is



The catalyst is usually warmed to approximately 300 °C to start the reaction, but after a short reaction time the copper catalyst often melts.

- (i) Give a reason why the catalyst is warmed and a reason why the catalyst may melt. (2)

.....

.....

.....

.....

.....

.....

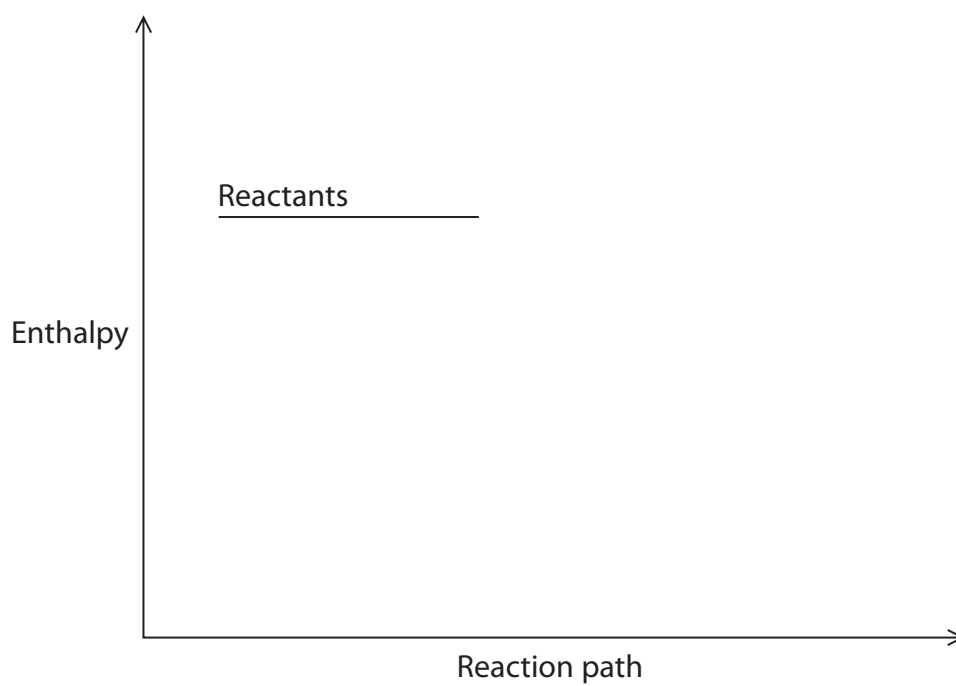
.....

.....



- (ii) Complete the reaction profile for this catalysed oxidation of ammonia, showing the enthalpy change,  $\Delta_r H$ .

(2)



DO NOT WRITE IN THIS AREA

DO NOT WRITE IN THIS AREA

DO NOT WRITE IN THIS AREA



- (iii) Describe the processes that occur on the surface of a heterogeneous catalyst during the oxidation of ammonia in air.

(3)

(Total for Question 9 = 17 marks)

**TOTAL FOR PAPER = 80 MARKS**



# The Periodic Table of Elements

|                               |                               |                                                                                       |                                     |                               |                               |                               |                                  |                                    |                                   |                                                                                        |                                |                             |                              |                               |                               |                               |                                |                               |                               |                            |                            |      |      |      |      |      |      |  |
|-------------------------------|-------------------------------|---------------------------------------------------------------------------------------|-------------------------------------|-------------------------------|-------------------------------|-------------------------------|----------------------------------|------------------------------------|-----------------------------------|----------------------------------------------------------------------------------------|--------------------------------|-----------------------------|------------------------------|-------------------------------|-------------------------------|-------------------------------|--------------------------------|-------------------------------|-------------------------------|----------------------------|----------------------------|------|------|------|------|------|------|--|
| 1                             | 2                             | <div>1.0<br/>H<br/>hydrogen<br/>1</div>                                               |                                     |                               |                               |                               |                                  |                                    |                                   |                                                                                        |                                | 3                           | 4                            | 5                             | 6                             | 7                             | 0 (8)<br>(18)                  |                               |                               |                            |                            |      |      |      |      |      |      |  |
|                               |                               | Key                                                                                   |                                     |                               |                               |                               |                                  |                                    |                                   |                                                                                        |                                |                             |                              |                               |                               |                               |                                |                               |                               |                            |                            |      |      |      |      |      |      |  |
|                               |                               | <div>relative atomic mass<br/>atomic symbol<br/>name<br/>atomic (proton) number</div> |                                     |                               |                               |                               |                                  |                                    |                                   |                                                                                        |                                |                             |                              |                               |                               |                               |                                |                               |                               |                            |                            |      |      |      |      |      |      |  |
| (1)                           | (2)                           | (3)                                                                                   |                                     |                               |                               |                               |                                  |                                    |                                   |                                                                                        |                                |                             |                              | (4)                           | (5)                           | (6)                           | (7)                            | (8)                           | (9)                           | (10)                       | (11)                       | (12) | (13) | (14) | (15) | (16) | (17) |  |
| 6.9<br>Li<br>lithium<br>3     | 9.0<br>Be<br>beryllium<br>4   | 23.0<br>Na<br>sodium<br>11                                                            | 24.3<br>Mg<br>magnesium<br>12       | 45.0<br>Sc<br>scandium<br>21  | 47.9<br>Ti<br>titanium<br>22  | 50.9<br>V<br>vanadium<br>23   | 52.0<br>Cr<br>chromium<br>24     | 54.9<br>Mn<br>manganese<br>25      | 55.8<br>Fe<br>iron<br>26          | 58.9<br>Co<br>cobalt<br>27                                                             | 58.7<br>Ni<br>nickel<br>28     | 63.5<br>Cu<br>copper<br>29  | 65.4<br>Zn<br>zinc<br>30     | 69.7<br>Ga<br>gallium<br>31   | 72.6<br>Ge<br>germanium<br>32 | 74.9<br>As<br>arsenic<br>33   | 79.0<br>Se<br>selenium<br>34   | 79.9<br>Br<br>bromine<br>35   | 126.9<br>I<br>iodine<br>53    | 131.3<br>Xe<br>xenon<br>54 | [222]<br>Rn<br>radon<br>86 |      |      |      |      |      |      |  |
| 85.5<br>Rb<br>rubidium<br>37  | 87.6<br>Sr<br>strontium<br>38 | 88.9<br>Y<br>yttrium<br>39                                                            | 88.9<br>Y<br>yttrium<br>39          | 88.9<br>Y<br>yttrium<br>39    | 91.2<br>Zr<br>zirconium<br>40 | 92.9<br>Nb<br>niobium<br>41   | 95.9<br>Mo<br>molybdenum<br>42   | [98]<br>Tc<br>technetium<br>43     | 101.1<br>Ru<br>ruthenium<br>44    | 102.9<br>Rh<br>rhodium<br>45                                                           | 106.4<br>Pd<br>palladium<br>46 | 107.9<br>Ag<br>silver<br>47 | 112.4<br>Cd<br>cadmium<br>48 | 114.8<br>In<br>indium<br>49   | 118.7<br>Sn<br>tin<br>50      | 121.8<br>Sb<br>antimony<br>51 | 127.6<br>Te<br>tellurium<br>52 | 126.9<br>I<br>iodine<br>53    | 126.9<br>I<br>iodine<br>53    | 131.3<br>Xe<br>xenon<br>54 | [222]<br>Rn<br>radon<br>86 |      |      |      |      |      |      |  |
| 132.9<br>Cs<br>caesium<br>55  | 137.3<br>Ba<br>barium<br>56   | 138.9<br>La*<br>lanthanum<br>57                                                       | 180.9<br>Ta<br>tantalum<br>73       | 183.8<br>W<br>tungsten<br>74  | 186.2<br>Re<br>rhenium<br>75  | 190.2<br>Os<br>osmium<br>76   | 192.2<br>Ir<br>iridium<br>77     | 195.1<br>Pt<br>platinum<br>78      | 197.0<br>Au<br>gold<br>79         | 192.2<br>Ir<br>iridium<br>77                                                           | 195.1<br>Pt<br>platinum<br>78  | 197.0<br>Au<br>gold<br>79   | 200.6<br>Hg<br>mercury<br>80 | 204.4<br>Tl<br>thallium<br>81 | 207.2<br>Pb<br>lead<br>82     | 209.0<br>Bi<br>bismuth<br>83  | [209]<br>Po<br>polonium<br>84  | [210]<br>At<br>astatine<br>85 | [210]<br>At<br>astatine<br>85 | [222]<br>Rn<br>radon<br>86 |                            |      |      |      |      |      |      |  |
| [223]<br>Fr<br>francium<br>87 | [226]<br>Ra<br>radium<br>88   | [227]<br>Ac*<br>actinium<br>89                                                        | [261]<br>Rf<br>rutherfordium<br>104 | [262]<br>Db<br>dubnium<br>105 | [264]<br>Bh<br>bohrium<br>107 | [277]<br>Hs<br>hassium<br>108 | [268]<br>Mt<br>meitnerium<br>109 | [271]<br>Ds<br>darmstadtium<br>110 | [272]<br>Rg<br>roentgenium<br>111 | Elements with atomic numbers 112-116 have been reported<br>but not fully authenticated |                                |                             |                              |                               |                               |                               |                                |                               |                               |                            |                            |      |      |      |      |      |      |  |

Elements with atomic numbers 112-116 have been reported but not fully authenticated

\* Lanthanide series

\* Actinide series

|     |    |         |    |       |    |              |    |     |    |           |    |       |    |            |    |       |    |           |    |       |    |           |    |       |    |            |    |       |    |           |    |       |    |             |    |       |    |             |    |       |    |         |     |       |    |              |     |       |    |           |     |       |    |            |     |
|-----|----|---------|----|-------|----|--------------|----|-----|----|-----------|----|-------|----|------------|----|-------|----|-----------|----|-------|----|-----------|----|-------|----|------------|----|-------|----|-----------|----|-------|----|-------------|----|-------|----|-------------|----|-------|----|---------|-----|-------|----|--------------|-----|-------|----|-----------|-----|-------|----|------------|-----|
| 140 | Ce | cerium  | 58 | 141   | Pr | praseodymium | 59 | 144 | Nd | neodymium | 60 | [147] | Pm | promethium | 61 | 150   | Sm | samarium  | 62 | 152   | Eu | europium  | 63 | 157   | Gd | gadolinium | 64 | 159   | Tb | terbium   | 65 | 163   | Dy | dysprosium  | 66 | 165   | Ho | holmium     | 67 | 167   | Er | erbium  | 68  | 169   | Tm | thulium      | 69  | 173   | Yb | ytterbium | 70  | 175   | Lu | lutetium   | 71  |
| 232 | Th | thorium | 90 | [231] | Pa | protactinium | 91 | 238 | U  | uranium   | 92 | [237] | Np | neptunium  | 93 | [242] | Pu | plutonium | 94 | [243] | Am | americium | 95 | [247] | Cm | curium     | 96 | [245] | Bk | berkelium | 97 | [251] | Cf | californium | 98 | [254] | Es | einsteinium | 99 | [253] | Fm | fermium | 100 | [256] | Md | mendeleevium | 101 | [254] | No | nobelium  | 102 | [257] | Lr | lawrencium | 103 |

