



MINISTRY OF EDUCATION, SINGAPORE in collaboration with CAMBRIDGE ASSESSMENT INTERNATIONAL EDUCATION General Certificate of Education Advanced Level Higher 1

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 CHEMISTRY
 8873/02

 Paper 2 Structured Questions
 October/November 2021

Candidates answer on the Question Paper. Additional Materials: Data Booklet

READ THESE INSTRUCTIONS FIRST

Write your Centre number, index number and name in the spaces provided at the top of this page.Write in dark blue or black pen.You may use an HB pencil for any diagrams or graphs.Do not use staples, paper clips, glue or correction fluid.DO **NOT** WRITE ON ANY BARCODES.

Section A Answer all the questions.

Section B Answer one question.

The use of an approved scientific calculator is expected, where appropriate.

The number of marks is given in brackets [] at the end of each question or part question.

This document consists of 20 printed pages.



Singapore Examinations and Assessment Board

Cambridge Assessment

2 hours



Section A

Answer **all** the questions in this section in the spaces provided.

1 The element platinum can be used as a heterogeneous catalyst in the removal of oxides of nitrogen from car exhaust gases.

Using platinum in the form of nanoparticles increases its efficiency as a catalyst.

When the pressure of a gas is increased, the molecules move closer together.

(a) (i) State the meaning of the term *heterogeneous catalyst*.

A heterogeneous catalyst is a substance which is different in phase from the reactants,

and increases the rate of a reaction by providing an alternative reaction pathway with

lower activation energy, while remaining chemically unchanged at the end of the

reaction.

[3]

(ii) State which feature of platinum nanoparticles explains the increase in platinum's efficiency as a catalyst.

The large surface area to volume ratio of platinum nanoparticles.

......[1]

(iii) The size of nanoparticles can make them hazardous to health.

Give an example of how nanoparticles can cause a potential health hazard. Inhaled nanopartciles can be deposited throughout the human respiratory system, followed by translocation potentially to the brain, liver and spleen. In view of the larger surface area, nanoparticles may show an increased toxicity compared to larger [1] particles of the same chemical composition.







(b) (i) Catalytic converters remove NO and CO from car exhaust gases.

$$2CO(g) + 2NO(g) \rightarrow N_2(g) + 2CO_2(g)$$

3

Explain why this is a redox reaction. Include oxidation numbers in your answer.

CO is oxidised to CO_2 since the oxidation number of carbon increases from +2 in CO to +4 in CO_2 , while NO is reduced to N₂ since the oxidation number of nitrogen decreases from +2 in NO to 0 in N₂.

- (ii) Suggest why increasing the pressure will increase the rate of this reaction.

Increasing the pressure causes the gas molecules to be closer together, therefore increasing the frequency of collision between the molecules. As a result, the frequency of effective collision also increases, leading to an increase in the rate of reaction. [1]

[Total: 8]





2 Vinegar contains ethanoic acid dissolved in water.

If the concentration of ethanoic acid is greater than 5% by mass then the vinegar has an unpleasant taste.

A student determines the concentration of ethanoic acid in a sample of vinegar by titrating it with aqueous sodium hydroxide.

$$CH_3COOH + NaOH \rightarrow CH_3COONa + H_2O$$

A 25.0 cm³ portion of the sample of vinegar is transferred into a 250 cm³ volumetric flask. The solution is made up to 250 cm³ with deionised water.

Several $25.0 \,\mathrm{cm^3}$ portions of this diluted vinegar are titrated against $0.0320 \,\mathrm{mol}\,\mathrm{dm^{-3}}$ sodium hydroxide, using thymolphthalein indicator. The mean volume of aqueous sodium hydroxide added is $16.20 \,\mathrm{cm^3}$.

(a) Calculate the concentration, in moldm⁻³, of ethanoic acid in the original sample of vinegar.

$$n_{\text{NaOH}} = \frac{16.20}{1000} \times 0.0320 = 5.184 \times 10^{-4} \text{ mol}$$

$$n_{\text{CH}_{3}\text{CO}_{2}\text{H}} \text{ in } 25.0 \text{ cm}^{3} \text{ of diluted vinegar} = n_{\text{NaOH}} = 5.184 \times 10^{-4} \text{ mol}$$

$$n_{\text{CH}_{3}\text{CO}_{2}\text{H}} \text{ in } 250 \text{ cm}^{3} \text{ of diluted vinegar} = \frac{250}{25.0} \times 5.184 \times 10^{-4} \text{ mol} = 5.184 \times 10^{-3} \text{ mol}$$

$$n_{\text{CH}_{3}\text{CO}_{2}\text{H}} \text{ in } 25.0 \text{ cm}^{3} \text{ of sample} = n_{\text{CH}_{3}\text{CO}_{2}\text{H}} \text{ in } 250 \text{ cm}^{3} \text{ of diluted vinegar}$$

$$= 5.184 \times 10^{-3} \text{ mol}$$

$$[\text{CH}_{3}\text{CO}_{2}\text{H}] \text{ in original sample} = \frac{5.184 \times 10^{-3} \text{ mol}}{\frac{25.0}{1000}} = 0.20736$$

$$\approx \underline{0.207 \text{ mol dm}^{-3}}$$

(b) Calculate the percentage by mass of ethanoic acid in the original sample of vinegar.

State whether the vinegar would taste pleasant or unpleasant. Assume the density of vinegar to be $1 \, \text{g} \, \text{cm}^{-3}$.

 $\begin{bmatrix} CH_{3}CO_{2}H \end{bmatrix} = 0.20736 \text{ mol } dm^{-3}$ = 0.20736 mol × (2×12.0 + 4×1.0 + 2×16.0 g mol^{-1}) dm^{-3} ≈ 12.44 g dm^{-3}

Assuming a density of 1 g cm⁻³, this translates to 12.44 g of CH₃CO₂H in 1000 g of vinegar [2]

% by mass of ethanoic acid = $\frac{12.44 \text{ g}}{1000 \text{ g}} \times 100\% = 1.24\%$

Since the % by mass of ethanoic acid is below 5%, the vinegar would taste pleasant.

[3]



(c) The student repeats the experiment using a different indicator. Using this indicator the mean volume of aqueous sodium hydroxide used in the titration is lower.

5

Explain how titrating using a different indicator can give a smaller mean volume of aqueous sodium hydroxide than when thymolphthalein indicator is used.

The end-point of a weak acid-strong base titration like in this case has a pH > 7. If the working range of the indicator is below that of the end-point pH and before the region of rapid pH increase, it will change colour before the end-point, leading to a smaller mean titre volume. [1]

(d) Ethanoic acid is a weak acid.

 $CH_3COOH \rightleftharpoons CH_3COO^- + H^+$

It can be mixed with aqueous sodium ethanoate to make a buffer solution.

(i) Explain what is meant by the term *buffer solution*.

A buffer solution is one that is capable of resisting pH changes when small amount of

- (ii) Explain, by reference to the equilibrium in (d), how this mixture behaves as a buffer.
 When small amount of an acid is added, the equilibrium shifts to the left thereby
 removing the acid. When a small amount of a base is added, the base is removed by
 the H⁺, where the equilibrium shifts right to replenish the H⁺. Since small amount of
 acid and base is removed, the pH remains relatively constant. [3]
- (e) 1.02g of metal X reacts with excess ethanoic acid forming 0.912 dm³ of hydrogen gas.

$$X + 2CH_3COOH \rightarrow (CH_3COO)_2X + H_2$$

Identify metal X.

The gas volume is measured at r.t.p.

$$n_{\rm H_2} = \frac{0.912}{24.0} = 0.0380 \text{ mol}$$

$$n_{\rm X} = n_{\rm H_2} = 0.0380 \text{ mol}$$

$$A_{\rm F}({\rm X}) = \frac{1.02}{0.0380} = 26.84$$
[2]
[Total: 12]

Since X is divalent, it is likely to be magnesium.





3 Polystyrene, nylon 6, Terylene (poly(ethylene terephthalate) (PET)) and neoprene are all polymers.

6

- (a) Complete the boxes in Table 3.1.
- (b) Suggest why Terylene is used to make shirts.

Terylene has high tensile strength and ability to stretch and is less prone to creasing. [1]

(c) (i) Draw and label the structures of the *cis* and *trans* isomers of the neoprene repeat unit.



[8]

(ii) Explain why the neoprene repeat unit is able to exist as *cis* and *trans* isomers.

This is because there is restriction rotation about the C=C and each of the double bond C has two different substitutents on it.

.....[2]

(d) A student tries to remove a stain from a Terylene shirt using sodium hydroxide. Explain, in terms of the structure of Terylene, why this is unwise.

The ester functional group in Terylene may undergo alkaline hydrolysis when treated with sodium hydroxide. [1]

[Total: 13]





Table 3.1



(a) A mixture of gaseous reactants and products was allowed to reach equilibrium.

The effects on the equilibrium yield of the products caused by changes in the pressure and in the temperature of the gaseous mixture are shown in the graph.



(i) Deduce whether the forward reaction is exothermic or endothermic.

Explain your answer using references to the graph and to the equilibrium position.
At any given pressure, the yield increases with temperature, meaning that the position of equilibrium lies more to the right (product side), favouring the forward reaction.
Hence, the forward reaction is endothermic as the system attempts to counter the increase in temperature by absorbing heat.

(ii) Deduce whether the forward reaction involves an increase or decrease in the total number of molecules in the gaseous mixture.

Explain your answer using references to the graph and to the equilibrium position.

At any given temperature, the yield increases with pressure, meaning that the position

of equilibrium lies more to the right, favouring the forward reaction. Hence, the forward

reaction involves a **decrease** in the total number of molecules as the system attempts

to counter the increase in pressure by reducing the number of gaseous molecules. [2]

(b) (i) When the temperature of a reaction mixture is increased, the reaction rate increases.

Explain this in terms of the Boltzmann distribution.

When temperature increases, the proportion of molecules with energy more than or equal to the activation energy increases. Also, the average kinetic energy of the molecules increases, increasing the frequency of collision. Both leads to an increase [2] in the frequency of effective collsion and hence the rate of reaction.







(ii) State the effect that increasing the temperature has on the rate constant for a reaction.

9

Explain your answer.

Increasing the temperature increases the rate constant for a reaction since the

proportion of molecules with energy greater or equal to the activation energy increase

(c) Hydrogen is produced in industry from methane, CH_4 , and steam, H_2O .

$$CH_4(g) + 2H_2O(g) \iff CO_2(g) + 4H_2(g)$$

This reaction occurs in two stages.

Stage 1

 $CH_4(g) + H_2O(g) \iff CO(g) + 3H_2(g) \qquad \Delta H = +210 \text{ kJ mol}^{-1}$

Stage 2

$$CO(g) + H_2O(g) \iff CO_2(g) + H_2(g) \qquad \Delta H = -42 \text{ kJ mol}^{-1}$$

Complete and label the reaction pathway diagram for the overall reaction between CH_4 and H_2O showing both of these stages.



[Total: 11]







10

(a) (i) Complete the electronic configurations of the species K^+ , O and Fe.

| $K^{+} 1s^{2} \frac{2s^{2} 2p^{6} 3s^{2} 3p^{6}}{2s^{2} 3p^{6}}$ | |
|--|--|
| O 1s ² 2s ² 2p ⁴ | |
| Fe 1s ² 2s ² 2p ⁶ 3s ² 3p ⁶ 3d ⁶ 4s ² | |

(ii) The magnetic properties of a substance depend on how its electrons are arranged.

Diamagnetic substances have all of their electrons paired. A diamagnetic substance is slightly repelled by a magnetic field.

Paramagnetic substances contain unpaired electrons. A paramagnetic substance is slightly attracted by a magnetic field.

Using this information and your electronic configurations in (a)(i), predict whether each of the species K^+ , O and Fe is expected to be diamagnetic or paramagnetic.

| K+ | diamagnetic |
|----|--------------|
| 0 | paramagnetic |
| Fe | paramagnetic |
| | [1] |







(b) Name the shape and state the bond angles in a molecule of water, H₂O, and in an oxonium ion, H₃O⁺.

11

Explain your answers using the Valence Shell Electron Pair Repulsion (VSEPR) theory. You may draw diagrams to illustrate your answers.

H₂O



Bent shape with bond angle of **105°**. There are two σ bond pairs and two lone pairs of electrons around the central O, which will arrange themselves in a tetrahedral geometry to minimise repulsion. As lone pairs are closer to the O, they occupy more space resulting in compression of the H–O–H bond angle from the ideal tetrahedral angle of 109.5° to 105°. H₃O⁺



Trigonal pyramidal shape with bond angle of **107°**. There are three σ bond pairs and one lone pair of electrons around the central O, which will arrange themselves in a tetrahedral geometry to minimise repulsion. Since there is only one lone pair in H₃O⁺, the compression of the H–O–H from the ideal 109.5° is less severe, giving an angle of 107°. [7]

[Total: 11]









6 A chemical company is planning to manufacture a new drug to sell worldwide.

The new drug can be manufactured using one of three different processes, which are labelled **A**, **B** and **C** in Table 6.1.

12

The chemical company must decide which of these three processes to use.

Atom economy is a measure of the amount of starting materials which are in the final product and is one of the factors which is considered for drug manufacturing processes. The atom economy of a process can be calculated using the formula:

atom economy = $\frac{\text{mass of atoms in the drug}}{\text{mass of all atoms in the reactants}}$

The chemical company wants to make the drug in large quantities and as cheaply as possible. However, they must also consider the effect the process might have on the environment.

None of these processes is perfect, each has problems associated with it.

| process | Α | В | С |
|-------------------------------------|---|-------------------------------------|-------------------------------------|
| number of stages | 4 | 5 | 3 |
| raw material availability | made to order by a company 200km away from the factory | readily available locally | made to order by a company overseas |
| raw material cost | high | medium | very high |
| overall energy input at the factory | 150 kJ mol ⁻¹ | 250 kJ mol ⁻¹ | 750 kJ mol ⁻¹ |
| solvents used | high boiling point, toxic | volatile, relatively harmless | water |
| atom economy | 60% | 90% | 80% |
| overall yield | 90% | 60% | 60% |
| waste | toxic | harmless | toxic |

Table 6.1





Consider each of the properties in Table 6.1.

Suggest which process, **A**, **B** or **C**, would be the most suitable for manufacturing the new drug.

Explain your answer in terms of cost, environmental issues and the need to produce large amounts of the drug. You should make reference to each of the properties listed in Table 6.1. Number of stages primarily affects the startup cost in terms of the design of the manufacturing plant. In this case, the number of stages required for process A, B and C are not very different and so does not significantly favour or disfavour any one of the process. Besides the direct cost of the raw material, its availability will affect the operating cost as well due to the need to factor in transportation cost. In addition, if the raw material needs to be made to order, it will further increase the cost as it will entails having to pre-order and store the raw material to meet the requirement of producing large amounts of the drug. Hence these two factors render process **B** especially attractive, while disfavouring process **C** severely. The overall energy input required per mole of the drug will affect the operating cost due to the cost of electricity. This many also have a negative impact on the environment, particularly so if the electricity originates from the burning of fossil fuel. This will again severely disfavour process C, while slightly favouring process A, although the advantage over process B is marginal. The toxicity of the solvent used will present environmental issues as the solvent eventually will be discarded into the environment. The volatility of the solvent on the other hand affects the ease of isolation of the products, with a volatile solvent being more easily removed and recovered. The atom economy, which reflects the efficiency of the reactions involved, should be considered together with the overall yield, which gives an indication of the amount of drug obtained. Although a high overall yield is desirable, however, if the atom economy is low, it would mean that a lot of undesirable by-products will be produced at the same time, which will be discarded into the environment, posing potential environmental issues if these wastes are toxic. The solvent used, atom economy, overall yield and toxicity of waste, taken together all [Total: 5] renders process A highly undesirable, while process B will be substantially favoured over process **C**, particularly if large amounts of the drug is to be made.

All in all, weighing all the different factors, process **B** will be the most suitable for manufacturing

the new drug.

ġ.



Section B

Answer one question from this section in the spaces provided.

- 7 (a) State and explain the difference in the radii of each of the pairs of species in (a)(i) and (a)(ii).
 The radii can be found in the *Data Booklet*.
 - (i) Atomic radii of a sulfur atom and a chlorine atom.

S atom has a larger atomic radii than a C*l* atom since the C*l* nucleus has one more proton than the S nucleus, but shielding effect is similar as they have the same number of core electrons. Hence effective nuclear charge experienced by the valence electrons is higher in C*l*, pulling the valence electrons closer, hence a smaller atomic radii.

(ii) Ionic radii of a sodium ion and a sulfide ion.

The S_2 anion has one additional filled quantum shell of core electrons compared to theNa, cation, hence ionic radii of Na, is smaller than that of S_2 .

(b) (i) State what is meant by the term *electronegativity*.

Electronegativity refers to the power of an atom to attract electrons to itself.

(ii) State how the bonding in the oxides of the elements sodium to sulfur changes across Period 3.

Explain this change in terms of the electronegativities of these elements.

Bonding changes from ionic bonds in Na²O and MgO, to ionic bonds with covalent character in A¹²O³, to polar covalent bonds in SiO², P⁴O¹⁰ and SO³, since the difference in electronegativity between the element and O decreases, as electronegativity of the [2] elements increases across Period 3.





(c) Deduce whether SF_6 is a polar molecule. Explain your answer.

SF₆ consists of six polar S–F bonds arranged in an octahedral manner around the S.

Although the S–F bonds are polar, however, the polarity of bonds cancel exactly due to the

symmetrical shape of the molecule, resulting in a **non-polar molecule**.

......[2]

(d) The properties of methylamine, CH₃NH₂, are affected by the strong intermolecular forces present between methylamine molecules.

Draw a labelled diagram to name and show the strongest intermolecular force present.

Your diagram should include two methylamine molecules.

hydrogen bond

[3]







- (e) Atoms use s and p orbitals to form σ bonds and π bonds.
 - (i) Draw a labelled diagram to show how s and p orbitals form a σ bond.



(ii) Draw a labelled diagram to show the formation of a π bond.



(iii) Draw the displayed formula of 3-methylbut-2-enoic acid, (CH₃)₂CCHCOOH.

Deduce the number of σ and π bonds in this molecule.



14 σ and 2 π bonds

[2]

[1]

[1]





(f) A sample of element X contains three isotopes.

Data for two of the isotopes present in this sample of **X** are shown in Table 7.1.

| mass number | abundance |
|-------------|-----------|
| 54 | 36.24% |
| 57 | 52.35% |

Table 7.1

The sample of **X** has a relative atomic mass, A_r , of 55.79.

Calculate the mass number of the third isotope.

Let the mass number of the third isotope be *m*. $\frac{54 \times 36.24 + 57 \times 52.35 + m \times (100 - 36.24 - 52.35)}{100} = 55.79$ 4940.91 + 11.41m = 5579 $m = 55.92 \approx 56$ The mas number of the third isotope is <u>56</u>.

(g) Calculate the pH of a sample of sulfuric acid of concentration $0.0125 \,\text{mol}\,\text{dm}^{-3}$.

You should assume that the sulfuric acid is completely dissociated into H^+ and SO_4^{2-} ions.

 $\begin{bmatrix} H^{+} \end{bmatrix} = 2[H_{2}SO_{4}] = 2 \times 0.0125$ $= 0.0250 \text{ mol } dm^{-3}$ $pH = -lg[H^{+}] = -lg0.0250$ = 1.60

[1]

[3]

[Total: 20]





3 (a) (i) Define the term *first ionisation energy*.

First ionisation energy is the energy required to remove one mole of electrons from

one mole of gaseous atoms to give one mole of gaseous unipositive cation.

(ii) State the first ionisation energies of sodium and of phosphorus. Use data from the *Data Booklet.*

Explain why they are different.

First ionisation energy of sodium is 494 kJ mol⁻¹, of phosphorus is 1060 kJ mol⁻¹.

P with 15 protons in the nucleus, has a higher nuclear charge than Na with 11 protons.

Shielding is similar as they have the same $1s^2 2s^2 2p^6$ core. Thus the valence electrons

of P experiences higher effective nuclear charge, leading to a higher 1st I.E.

(iii) Explain why the first ionisation energy of phosphorus is greater than the first ionisation energy of sulfur.

Electronic configuration of P is [Ar] 3s² 3p³, S is [Ar] 3s² 3p⁴. First ionisation energy of

S involves removal of a paired 3p electron, which requires less energy due to inter-

electronic repulsion. [2]

(iv) Suggest, by considering the electronic configurations of these elements, why the first ionisation energies of the elements Sc to Zn are very similar.

Sc to Zn has electronic configuration of the form [Ar] 3dⁿ 4s² or [Ar] 3dⁿ 4s¹, where the 4s electrons are the outermost. For each proton added to the nucleus, one electron is added to the inner 3d subshell, which nullifies the increase in nuclear charge, hence [2] the effective nuclear charge experienced by the 4s electrons are very similar, leading to very similar first ionisation energy.





(b) When oxidation and reduction occur there is a movement of electrons.

The unit of charge is the coulomb, C.

The charge on an electron, given to three significant figures, is -1.60×10^{-19} coulombs.

(i) Calculate the charge, in coulombs, of 1 mole of electrons.

Use of the Data Booklet is required.

Charge of one mole of electrons = $-1.60 \times 10^{-19} \times 6.02 \times 10^{23}$ = $-96320 \approx -9.63 \times 10^4 \text{ C}$ [1]

(ii) Calculate the charge flowing, in coulombs, when 2.5 moles of bromine molecules are formed in a displacement reaction between chlorine molecules and bromide ions.

 $2Br^{-} \rightarrow Br_{2} + 2e^{-} \qquad n_{e^{-}} = 2n_{Br_{2}} = 5.0 \text{ mol}$ charge flowing = $n_{e^{-}} \times -96320 = 5.0 \times -96320$ $= -481600 \approx -4.82 \times 10^{5} \text{ C} \qquad [2]$

(c) Use data from Table 8.1 and the energy cycle to calculate the standard enthalpy change of formation of benzene, ΔH_{f}^{Φ} .

$$\begin{array}{ccc} 6\mathrm{C}(\mathrm{s}) &+ 3\mathrm{H}_{2}(\mathrm{g}) & \xrightarrow{\Delta H_{\mathrm{f}}^{\Phi}} & \mathrm{C}_{6}\mathrm{H}_{6}(\mathrm{I}) \\ &+ 7\frac{1}{2}\mathrm{O}_{2}(\mathrm{g}) & \swarrow & \swarrow & + 7\frac{1}{2}\mathrm{O}_{2}(\mathrm{g}) \\ & & 6\mathrm{CO}_{2}(\mathrm{g}) &+ 3\mathrm{H}_{2}\mathrm{O}(\mathrm{I}) \end{array}$$

| substance | standard enthalpy change of combustion/kJmol ⁻¹ |
|-----------------------------------|--|
| C ₆ H ₆ (I) | -3267 |
| C(s) | 394 |
| H ₂ (g) | 286 |

Table 8.1

 $\Delta H_{f}^{\ominus} \left(\mathsf{C}_{6} \mathsf{H}_{6} \left(l \right) \right) = 6 \Delta H_{c}^{\ominus} \left(\mathsf{C} \left(s \right) \right) + 3 \Delta H_{c}^{\ominus} \left(\mathsf{H}_{2} \left(g \right) \right) - \Delta H_{c}^{\ominus} \left(\mathsf{C}_{6} \mathsf{H}_{6} \left(l \right) \right)$ $= \left(6 \times -394 \right) + \left(3 \times -288 \right) - \left(-3267 \right)$ $= <u>+39 \text{ kJ mol}^{-1}$ </u>

K?



(d) Compound X contains carbon, hydrogen and oxygen only.

X contains 53.3%, by mass, of carbon and 11.1%, by mass, of hydrogen.

The relative molecular mass, M_r , of **X** is 90.

(i) Calculate the empirical formula of **X**.

In 100 g of **X**,

| | С | Н | 0 |
|------------|----------------------------|---------------------------|----------------------------|
| mass / g | 53.3 | 11.1 | 35.6 |
| amt / mol | $\frac{53.3}{12.0} = 4.44$ | $\frac{11.1}{1.0} = 11.1$ | $\frac{35.6}{16.0} = 2.23$ |
| mole ratio | 2 | 5 | 1 |

Empirical formula of **X** is $\underline{C_2H_5O}$.

(ii) Deduce the molecular formula of **X**. Let the molecular formula of **X** be $(C_2H_5O)_n$.

$$n(2 \times 12.0 + 5 \times 1.0 + 16.0) = 90$$

 $45n = 90$
 $n = 2$

Molecular formula of X is $\underline{C_4H_{10}O_2}$.

(e) Compound Y has the molecular formula $C_4H_{10}O$.

Y reacts with ethanoic acid to produce a sweet smelling liquid.

One of the carbon atoms in Y has four different atoms or groups of atoms attached to it.

(i) Draw the displayed formula of Y.



[1]

(ii) Draw the structure of the functional group present in the sweet smelling liquid.



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[3]

[1]

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