OCR
RECOGNISING ACHIEVEMENT

OXFORD CAMBRIDGE AND RSA EXAMINATIONS

Advanced GCE

CHEMISTRY (SALTERS) 2854

Chemistry by Design

Friday **23 JANUARY 2004** Afternoon 2 hours

Candidates answer on the question paper.
Additional materials:
Data Sheet for Chemistry (Salters)
Scientific calculator

Candidate Name	Centre Number	Candidate Number

TIME 2 hours

INSTRUCTIONS TO CANDIDATES

- Write your name in the space above.
- Write your Centre number and Candidate number in the boxes above.
- Answer **all** the questions.
- Write your answers in the spaces provided on the question paper.
- Read each question carefully and make sure you know what you have to do before starting your answer.

INFORMATION FOR CANDIDATES

- The number of marks is given in brackets [ ] at the end of each question or part question.
- You will be awarded marks for the quality of written communication where this is indicated in the question.
- You may use a scientific calculator.
- You may use the *Data Sheet for Chemistry (Salters)*.
- You are advised to show all the steps in any calculations.

FOR EXAMINER'S USE		
Qu.	**Max.**	**Mark**
1	**22**	
2	**33**	
3	**19**	
4	**28**	
5	**18**	
TOTAL	**120**	

This question paper consists of 16 printed pages.

Registered Charity Number: 1066969
[Turn over

Answer **all** the questions.

1 The structures of many minerals are based on silicate tetrahedra. Silicate rocks and clays are examples of naturally-occurring minerals. *Aerogels* are new synthetic silicate materials used as thermal or electrical insulators.

(a) How many electrons are in the outer shell of a silicon atom?
Explain your reasoning.

.....

.....[2]

(b) The SiO_4^{4-} ion is tetrahedral.

(i) Draw a dot–cross diagram for the SiO_4^{4-} ion, showing the outer electron shells only.

[3]

(ii) Explain why the shape of the SiO_4^{4-} ion is tetrahedral.

.....

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.....[3]

(c) **(i)** Some minerals consist of sheets of silicate tetrahedra. Explain how metal ions are attracted to these sheets.

.....

.....[1]

(ii) Clays have sheets of octahedra in addition to the silicate sheets. Name the most common element at the centre of each octahedron.

.....[1]

(d) Some metal ions attracted to clays are lithium, sodium and potassium. The table shows the ionic radii for the gaseous cations.

ion	radius / nm
Li^+	0.078
Na^+	0.098
K^+	0.133

(i) Explain why the lithium ion is smaller than the sodium ion.

.....

.....[1]

(ii) Which of these ions, when in **aqueous solution**, would you expect to be bound most strongly to a clay surface? Explain your answer.

.....

.....

.....[3]

(e) In this question, two marks are available for the quality of use and organisation of scientific terms.

Aerogels are porous silicate materials. When used as insulators, the pores are often filled with carbon dioxide.

Describe **two** ways in which the **physical** properties of CO_2 and SiO_2 differ (at room temperature). Explain the differences in terms of their structure and bonding.

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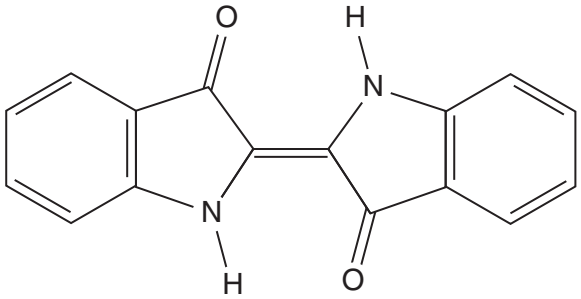
.....[6]

Quality of Written Communication [2]

[Total: 22]

2 In 1884, Vincent van Gogh wrote a letter to his brother Theo, describing a painting in terms of its contrasting blue tones. In the letter, he talks about 'indigo tones' and 'cobalt tones'. These refer to two blue pigments indigo and cobalt blue.

(a) Indigo is a blue pigment, used to dye jeans. It is also used as a pigment for paints. Its structure is shown below.



indigo

(i) **Name three** functional groups in indigo (not including aromatic rings).

.....

.....[3]

(ii) Write down the number of carbon atoms in an indigo molecule.

.....[1]

(iii) Explain why indigo is described as a *trans* isomer.

.....

.....[1]

(iv) Why does *cis-trans* isomerism arise?

.....

.....[1]

(b) Cobalt blue has the formula $CoO.Al_2O_3$.

(i) How does the position of cobalt in the Periodic Table indicate that it might form coloured compounds?

.....[1]

(ii) Cobalt blue is made by heating a mixture of precise amounts of cobalt chloride, $CoCl_2.6H_2O$, and aluminium chloride, $AlCl_3$.

A possible reaction sequence starts with aluminium chloride reacting with the water of crystallisation from the cobalt chloride:

$$AlCl_3 + 3H_2O \longrightarrow Al(OH)_3 + 3HCl$$

Write in the boxes the missing equations for the next steps in the sequence.

1 The cobalt ions react with hydroxide ions to give cobalt(II) hydroxide.

Equation: [ ]

2 The cobalt hydroxide and aluminium hydroxide decompose to give the oxides.

$$Co(OH)_2 \longrightarrow CoO + H_2O$$

Equation for the decomposition of aluminium hydroxide:

[ ]

[4]

(c) Cobalt blue is usually made by a batch process.

(i) What is meant by a *batch* process?

.....

.....[1]

(ii) Suggest a reason why a continuous process is **not** used.

.....

.....[1]

(iii) Suggest and explain a major safety hazard associated with the process of making cobalt blue described in **(b)(ii)**.

.....

.....[2]

(d) (i) Aluminium is an element in Period 3, Na to Ar. Aluminium chloride reacts with water to give hydrogen chloride.
Give the **formula of the chloride** of another element in this period which behaves in a similar way.

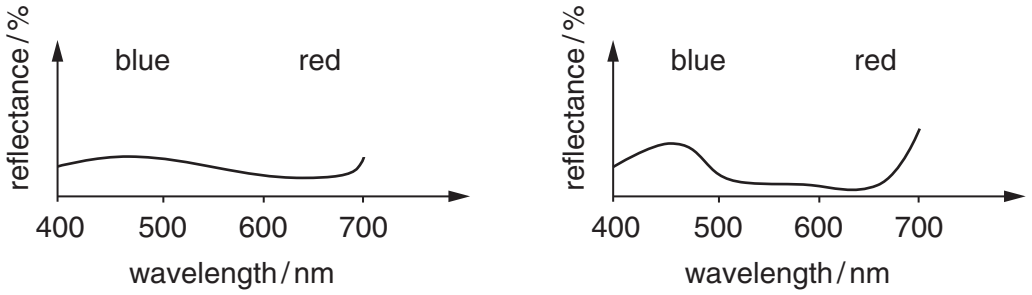
.....[2]

(ii) Calculate the mass of $CoCl_2.6H_2O$ that has the same amount in moles as 4.5 g of $AlCl_3$.
Give your answer to an appropriate number of significant figures.

A_r: Al, 27; Cl, 35.5; Co, 59; H, 1.0; O, 16

mass = ...g [5]

(e) (i) The reflectance spectra of indigo and cobalt blue are shown below.



indigo **cobalt blue**

Suggest how the colour of cobalt blue would look different from that of indigo.
Explain your answer.

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.....[2]

(ii) Explain, in terms of **energy levels**, why a blue substance looks blue.

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.....[4]

(f) Van Gogh's paints contained pigment and linseed oil.

(i) Linseed oil is a mixture of many different oils which are esters of carboxylic acids and glycerol (propane-1,2,3-triol). Draw a structural formula for the triester formed between glycerol and the carboxylic acid RCOOH.

[2]

(ii) Linseed oil is described as unsaturated. Explain the meaning of the term *unsaturated.*

.....

.....[1]

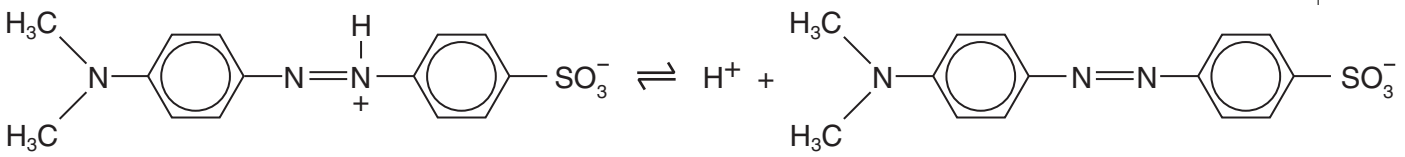
(iii) Describe a test and its result which would show that an oil is unsaturated.

.....

.....[2]

[Total: 33]

3 Methyl Orange is an azo dye that is used as an acid-base indicator. It acts as an indicator because of the equilibrium shown.



red form **yellow form**

(a) (i) Methyl Orange is added to a solution of a strong acid. What colour would the indicator show? Explain your answer.

.....

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.....[3]

(ii) Which group on Methyl Orange aids its solubility in water?

.....[1]

(b) Methyl Orange is a weak acid with pK_a = 3.7, K_a = 2.0 x 10^{-4} mol dm^{-3}.

(i) What is meant by a *weak* acid?

.....

.....[1]

(ii) Give the mathematical relationship between pK_a and K_a.

[1]

(iii) Give the expression for K_a in terms of [H^+], [yellow form] and [red form].

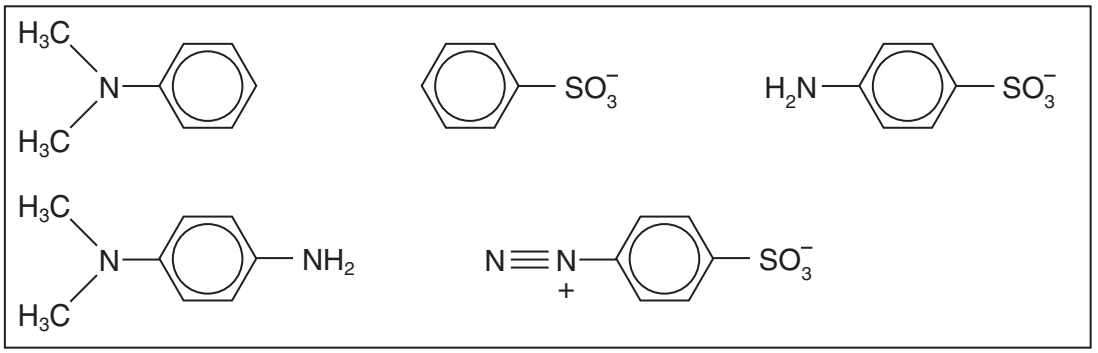
[2]

(iv) The 'mid-range pH' of an indicator occurs when there are equal concentrations of the two coloured forms present. Use your equation in **(iii)** and the data at the start of **(b)** to calculate the the mid-range pH for Methyl Orange. **Show your reasoning**.

pH = ... [2]

(c) The yellow form of Methyl Orange can be made by a coupling reaction.

(i) Choose, from the structures below, the **two** substances which would couple to give the yellow form of Methyl Orange. Circle the structures you have chosen.



[2]

(ii) Give **one** condition necessary for the **coupling** reaction to occur.

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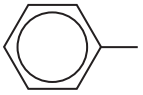
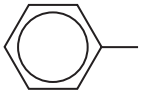
.....[1]

(d)  is the anion of the acid 

(i) Name this acid. .....[1]

(ii) Give the details of the reaction by which the acid can be made from benzene.

reagent which is added to benzene .....

reaction conditions .....[3]

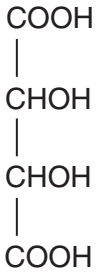
(iii) Circle **two** words below which describe the reaction mechanism.

nucleophilic electrophilic radical substitution addition elimination

[2]

[Total: 19]

4 All wines are slightly acidic and this contributes to their distinctive tastes. The commonest acid present in most wines is tartaric acid.



(a) (i) Write the **empirical** formula of tartaric acid.

.....[2]

(ii) Draw the **full structural** formula for tartaric acid.

[2]

(iii) Circle on your structure all the *chiral centres* in the tartaric acid molecule. [2]

(iv) Tartaric acid is said to be a *diprotic* acid. One mole of a diprotic acid reacts with two moles of aqueous sodium hydroxide. Write a balanced chemical equation for the reaction of tartaric acid with aqueous sodium hydroxide.

[3]

(v) A mixture of tartaric acid, sulphuric acid and potassium dichromate(VI) is heated under reflux. Suggest the structural formula of the product formed.

[2]

(b) The total acidity of wine can be worked out by titrating with aqueous sodium hydroxide.

(i) A 25.0 cm^3 sample of wine was neutralised by 12.0 cm^3 of 0.100 mol dm^{-3} sodium hydroxide. Calculate the amount in moles of H^+ ions in the 25.0 cm^3 sample of wine.

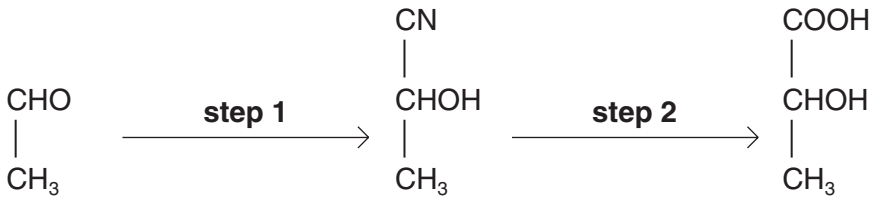
amount = ...mol [2]

(ii) Winemakers often describe the acidity of wine in units of 'grams of tartaric acid in 100 cm^3 wine'. They assume that all the acidity is caused by tartaric acid.
Calculate the acidity of the wine sample measured in these units.
Use your answer to **(b) (i)** and the facts that tartaric acid is diprotic and has an M_r of 150.

acidity = ...g tartaric acid in 100 cm^3 wine [3]

(c) Another acid often found in wine is lactic acid.

This can be made in the laboratory by a two-step route.



lactic acid

(i) Name the functional group in the starting compound.

.....[1]

(ii) Give the formula of the reagent used in **step 1**. .....[1]

(iii) Name the **type** of mechanism for the reaction in **step 1**.

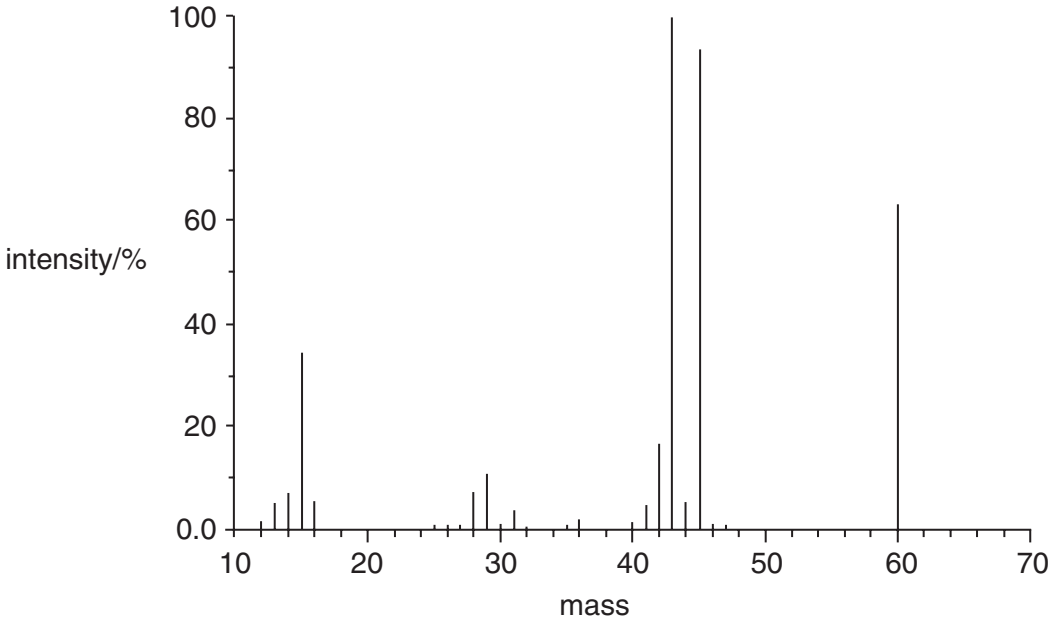
.....[2]

(iv) Use your Data Sheet to write down suitable reagents and conditions for **step 2**.

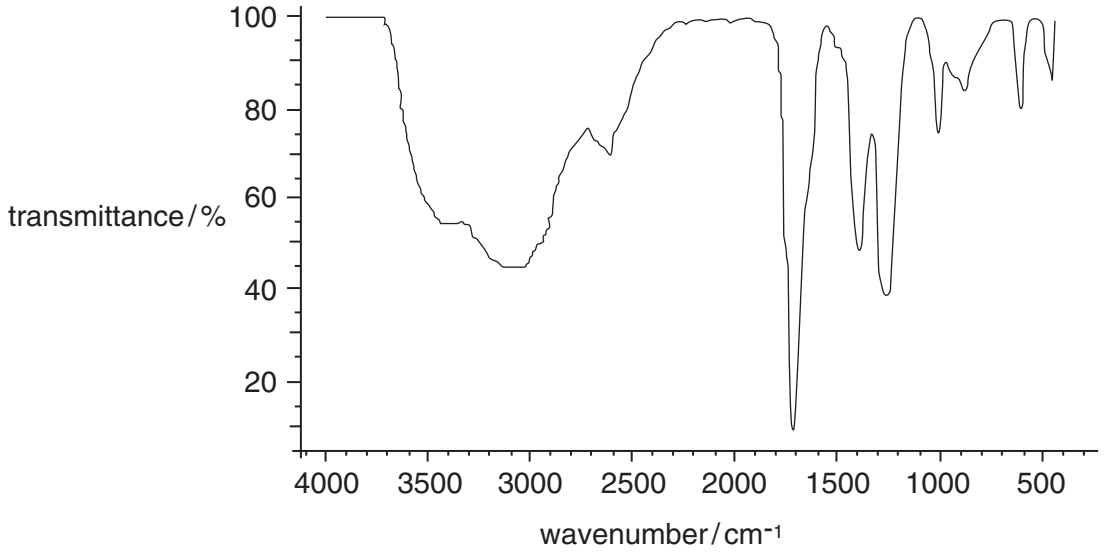
.....

.....[1]

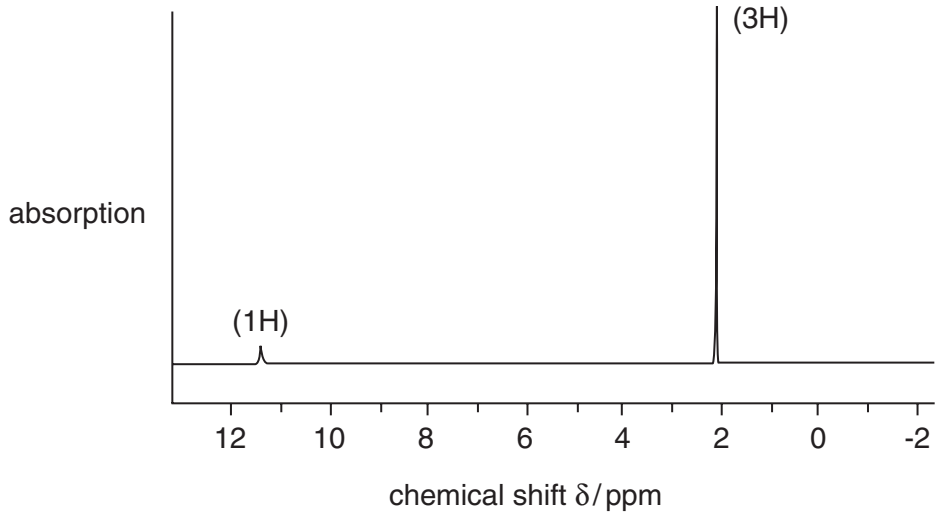
(d) Shown below are the mass spectrum, the infrared spectrum and the proton n.m.r spectrum of another substance which is found in wine.
Use the spectra and the Data Sheet to identify the substance, giving at least **two** pieces of evidence from each spectrum.



mass spectrum



infrared spectrum



nmr spectrum

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.....[7]

[Total: 28]

5 When sea-shells made of calcium carbonate fall to the deep ocean floor, they dissolve to form a solution of calcium ions and carbonate ions. One reason for this is the effect of decreasing temperature on the equilibrium shown.

$$CaCO_3(s) \rightleftharpoons Ca^{2+}(aq) + CO_3^{2-}(aq) \qquad \textbf{equation 5.1}$$

(a) The solubility of $CaCO_3$ increases at the lower temperatures of the deep ocean. Use Le Chatelier's principle to explain how you can deduce from this that the forward reaction in **equation 5.1** is exothermic.

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.....[2]

(b) Deep in an ocean, $K_{sp} = 1.0 \times 10^{-9}$ mol^2 dm^{-6} for calcium carbonate.

(i) Write the expression for the solubility product of calcium carbonate.

K_{sp} = ...[2]

(ii) Calculate whether calcium carbonate would precipitate in a solution where the concentrations of calcium ions and carbonate ions are both 1.0×10^{-5} mol dm^{-3}.

[3]

(c) **(i)** Use the entropy values in the table to calculate a value for the entropy change of the system for the forward reaction in **equation 5.1**.

	$S^{\ominus}$ / J K^{-1}mol^{-1}
$CaCO_3(s)$	+92.9
Ca^{2+} (aq)	–53.1
CO_3^{2-} (aq)	–56.9

ΔS_{sys} .....J K^{-1} mol^{-1} [2]

(ii) Use the expressions given below to explain why the exothermic reaction in **equation 5.1** is more likely to occur at low temperature**.**

$\Delta S_{total} = \Delta S_{sys} + \Delta S_{surr}$

$\Delta S_{surr} = -\frac{\Delta H}{T}$

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.....[3]

(d) In this question, one mark is available for the quality of spelling, punctuation and grammar.

Another reason why sea-shells dissolve deep in an ocean is that carbon dioxide is much more soluble there. This carbon dioxide reacts with the sea-shells to form soluble products.

Explain, giving details, why it would be useful to mankind to remove carbon dioxide from the atmosphere and 'bury' it deep in the oceans. Suggest why this is not being done.

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.....[5]

Quality of Written Communication [1]

[Total: 18]

END OF QUESTION PAPER