Diploma Programme
Programme du diplôme
Programa del Diploma

Chemistry
Higher level
Paper 3

Friday 12 May 2017 (morning)

Candidate session number

1 hour 15 minutes

Instructions to candidates

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

Section A	Questions
Answer all questions.	1 – 5

Section B	Questions
Answer all of the questions from one of the options.	
Option A — Materials	6 – 11
Option B — Biochemistry	12 – 17
Option C — Energy	18 – 23
Option D — Medicinal chemistry	24 – 29

2217 – 6109

37 pages

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Section A

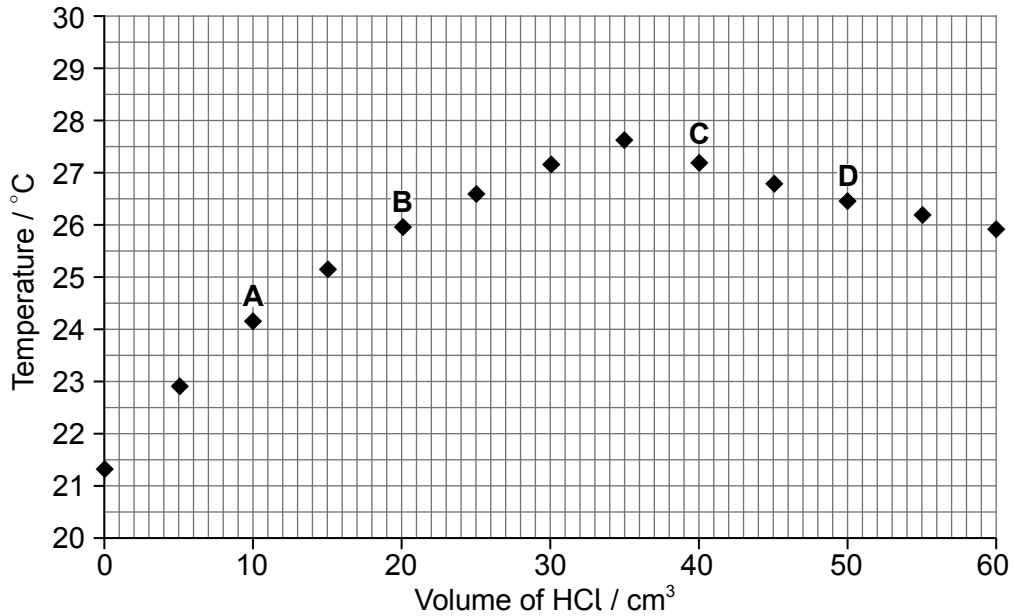
Answer **all** questions. Write your answers in the boxes provided.

A class was determining the concentration of aqueous sodium hydroxide by titrating it with hydrochloric acid, whilst monitoring the pH of the solution. The sodium hydroxide solution was added into a glass beaker from a measuring cylinder and the hydrochloric acid added using a burette. One group of students accidentally used a temperature probe rather than a pH probe. Their results are given below.

Volume of aqueous NaOH = $25.0 \pm 0.5\,cm^3$

Concentration of HCl = $1.00 \pm 0.01\,mol\,dm^{-3}$

Volume HCl $\pm$ 0.1 / cm^3	0.0	5.0	10.0	15.0	20.0	25.0	30.0	35.0	40.0	45.0	50.0	55.0	60.0
Temperature $\pm$ 0.1 / °C	21.3	22.9	24.2	25.1	25.9	26.6	27.2	27.6	27.2	26.8	26.5	26.2	25.9



1. (a) Calculate the percentage uncertainty of the volume of the aqueous sodium hydroxide. [1]

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(b) Suggest how the precision of this measurement could be improved. [1]

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2. (a) Deduce why more heat was produced in mixture **B** than in mixture **A**. [1]

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(b) Deduce why the temperature is higher in mixture **C** than in mixture **D**. [1]

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3. Suggest how the end point of the titration might be estimated from the graph. [1]

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4. State and explain how the graph would differ if 1 mol dm^{-3} sulfuric acid had been used instead of 1 mol dm^{-3} hydrochloric acid. [2]

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5. The graph of temperature against titre can be used to calculate the concentration of alkali without knowing the concentration of the hydrochloric acid, using the enthalpy of neutralization.

(a) Explain how the concentration may be calculated in this way. [2]

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(b) Heat losses would make this method less accurate than the pH probe method. Outline why the thermometric method would always give a lower, not a higher, concentration. [2]

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(c) Suggest how heat loss could be reduced. [1]

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(d) State **one** other assumption that is usually made in the calculation of the heat produced. [1]

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(This question continues on the following page)

(Question 5 continued)

(e) Suggest why scientists often make assumptions that do not correspond to reality. [1]

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(f) Outline why the thermochemical method would not be appropriate for 0.001 mol dm^{-3} hydrochloric acid and aqueous sodium hydroxide of a similar concentration. [1]

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Section B

Answer **all** of the questions from **one** of the options. Write your answers in the boxes provided.

Option A — Materials

6. Lanthanum, La, and antimony, Sb, form compounds with bromine that have similar formulas, $LaBr_3$ and $SbBr_3$.

(a) Determine the type of bond present in $SbBr_3$, showing your method. Use sections 8 and 29 of the data booklet. [2]

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(b) Lanthanum has a similar electronegativity to group 2 metals. Explain, in terms of bonding and structure, why crystalline lanthanum bromide is brittle. [2]

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7. Lanthanum metal may be produced by the electrolysis of molten $LaBr_3$.

(a) State why lanthanum cannot be produced by reducing its oxide with carbon. [1]

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(Option A continues on the following page)

(Option A, question 7 continued)

(b) Calculate the current (I), in A, required to produce 1.00 kg of lanthanum metal per hour. Use the formula $Q(\text{C}) = I(\text{A}) \times t(\text{s})$ and sections 2 and 6 of the data booklet. [3]

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8. (a) Lanthanum has a hexagonal close packed (hcp) crystal structure. State the coordination number of each lanthanum atom. [1]

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(b) Lanthanum becomes superconducting below 5 K. Explain, in terms of Bardeen–Cooper–Schrieffer (BCS) theory, how superconductivity occurs. [3]

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(c) Outline why superconductivity only occurs at low temperatures. [1]

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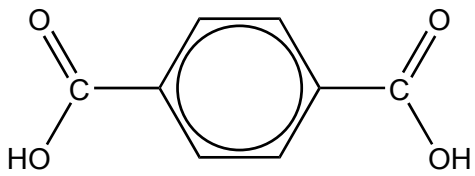
(Option A continues on the following page)

(Option A continued)

9. Antimony oxide is widely used as a homogeneous catalyst for the reaction of benzene-1,4-dicarboxylic acid with ethane-1,2-diol in the production of polyethylene terephthalate (PETE).



benzene-1,4-dicarboxylic acid

ethane-1,2-diol

(a) Deduce the repeating unit of the polymer and the other product of the reaction. [2]

Repeating unit:

Other product:

. . . . . .

(b) State the class of polymer to which PETE belongs. [1]

. . . . . .

(c) Catalysts reduce the activation energy. Outline how homogeneous catalysts are involved in the reaction mechanism. [1]

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(Option A continues on the following page)

(Option A, question 9 continued)

(d) Suggest why it is important to know how catalysts function. [1]

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(Option A continues on the following page)

(Option A continued)

10. Antimony and its compounds are toxic, so it is important to check that the catalyst is removed from the final product. One technique to detect antimony is Inductively Coupled Plasma Mass Spectroscopy (ICP-MS).

(a) Outline the nature of the plasma state and how it is produced in ICP-MS. [2]

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(b) Hydrogen sulfide could be used to remove antimony(III) ions from a solution.

Determine the concentration of antimony(III) ions that would be required to precipitate antimony(III) sulfide in a solution saturated with hydrogen sulfide.

$[S^{2-}]$ in water saturated with hydrogen sulfide $= 1.0 \times 10^{-14}\,\text{mol dm}^{-3}$
$K_{sp}\,(Sb_2S_3) = 1.6 \times 10^{-93}$ [3]

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(c) Identify a ligand that could be used to chelate antimony(III) ions in solution. [1]

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(Option A continues on page 12)

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

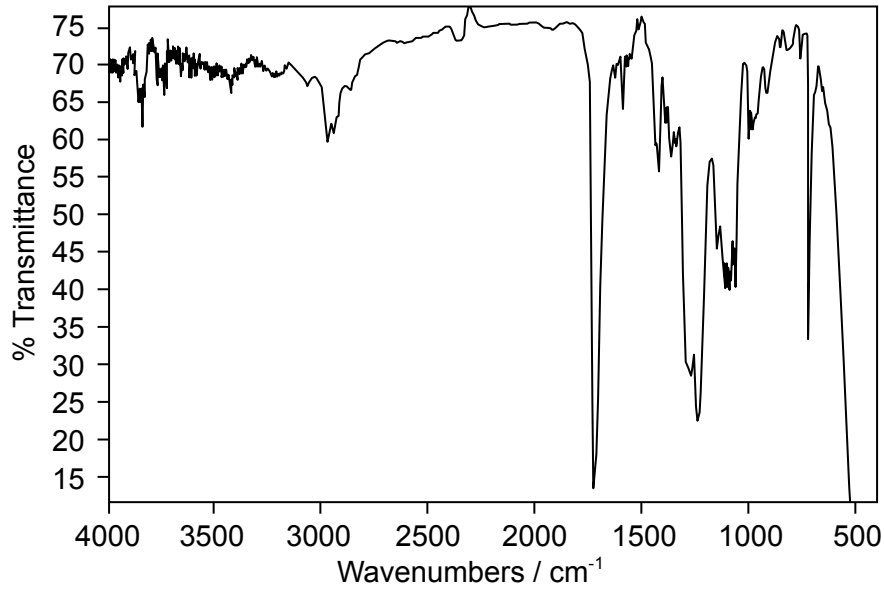
Answers written on this page
will not be marked.

(Option A continued)

11. Infrared (IR) spectroscopy is often used for the identification of polymers, such as PETE, for recycling.

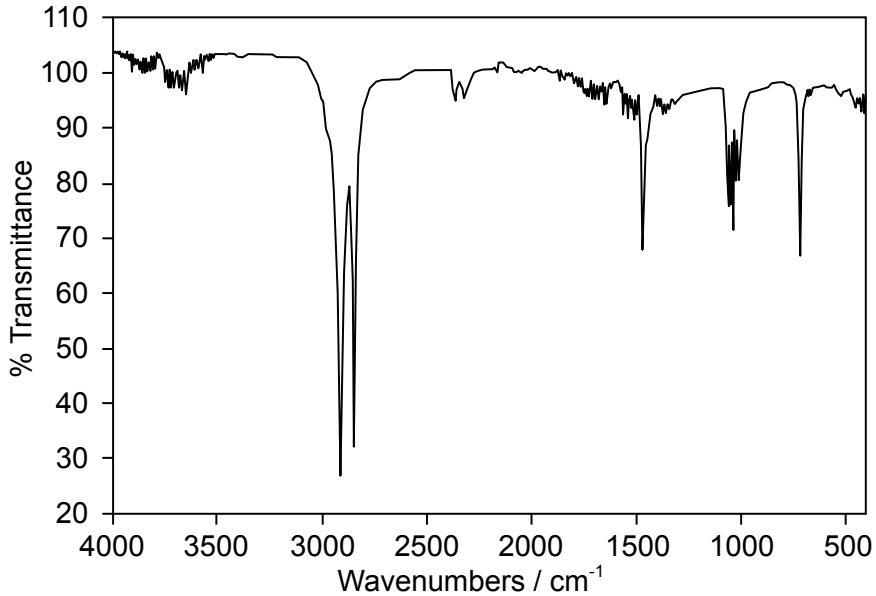
(a) Below are the IR spectra of two plastics (**A** and **B**); one is PETE, the other is low density polyethene (LDPE).

A



[Source: www.intechopen.com]

B



[Source: www.andersonmaterials.com]

(Option A continues on the following page)

(Option A, question 11(a) continued)

Deduce, giving your reasons, the identity and resin identification code (RIC) of **A** and **B** using sections 26 and 30 of the data booklet. [3]

A RIC:

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. . . . . .

. . . . . .

B RIC:

. . . . . .

. . . . . .

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(b) LDPE and high density polyethene (HDPE) have very similar IR spectra even though they have rather different structures and physical properties.

(i) Describe the difference in their structures. [1]

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(ii) Explain why the difference in their structures affects their melting points. [2]

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End of Option A

Option B — Biochemistry

12. Lipids and carbohydrates contain the same elements but have different properties.

The drain pipe of a kitchen sink can become clogged by fatty acids, such as linoleic acid, $C_{18}H_{32}O_2$, but not by the trisaccharide, raffinose, $C_{18}H_{32}O_{16}$, containing the same number of carbon atoms.

(a) (i) Explain why raffinose is far more water soluble than linoleic acid. [2]

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(ii) Solid fat triglycerides can also clog kitchen sink drains.

Explain how sodium hydroxide unblocks the drain. [2]

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(b) The amount of proteins, fats and carbohydrates determine the energy content of foods.

Explain why linoleic acid, $C_{18}H_{32}O_2$, is a more efficient energy storage molecule than raffinose, $C_{18}H_{32}O_{16}$. [2]

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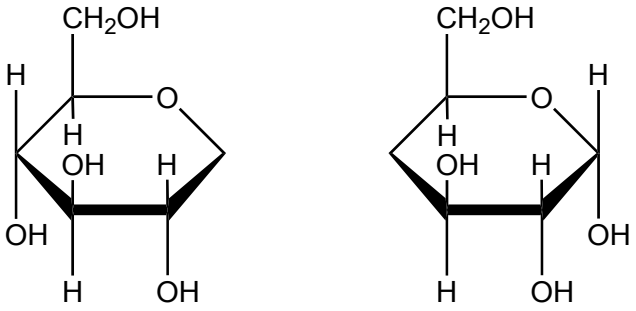
(Option B continues on the following page)

(Option B continued)

13. Sugars exist in both straight chain and ring forms.

(a) (i) Deduce the straight chain structure of ribose from its ring structure drawn in section 34 of the data booklet. [1]

(ii) Using the **partial** structure given, complete the structural formula of the molecule formed from the condensation of two cyclic α-glucose molecules. [1]



(b) Constructing models that allow visualizations of the stereochemistry of carbohydrates is essential to understand their structural roles in cells.

Describe how Haworth projections help focus on the position of attached groups. [1]

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(Option B continues on the following page)

(Option B, question 13 continued)

(c) Biodegradable plastics produced from starch present one solution to the environmental problem created by the use of large quantities of plastics.

(i) State **one** advantage of starch based polymers besides being biodegradable. [1]

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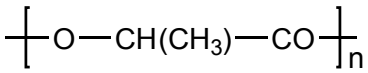
(ii) Biodegradable boxes made from polylactic acid, PLA, disintegrate when exposed to water.



Polylactic acid

State the formula of the product formed when water reacts with PLA. [1]

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(Option B continues on the following page)

(Option B continued)

14. Peptidase enzyme in the digestive system hydrolyses peptide bonds.

(a) Identify the type of metabolic process that occurs in the hydrolysis of the peptide during digestion. [1]

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(b) A tripeptide Ala-Asp-Lys was hydrolysed and electrophoresis of the mixture of the amino acids was carried out at a pH of 6.0. Refer to section 33 of the data booklet.

(i) Identify the **name** of the amino acid that does not move under the influence of the applied voltage. [1]

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(ii) Deduce, giving a reason, which amino acid will develop closest to the negative electrode. [2]

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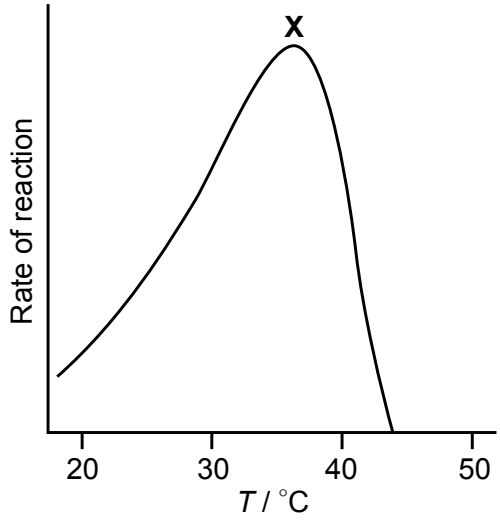
(Option B continues on the following page)

(Option B, question 14 continued)

(c) The breakdown of a dipeptide in the presence of peptidase was investigated between 18 °C and 43 °C. The results are shown below.



Comment on the rate of reaction at temperature **X** in terms of the enzyme's active site. [1]

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(d) The solubility of a vitamin depends on its structure.

Identify the vitamin given in section 35 of the data booklet that is the most soluble in water. [1]

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(e) Pollution from heavy metal ions has become a health concern.

Outline how the presence of heavy metal ions decreases the action of enzymes. [1]

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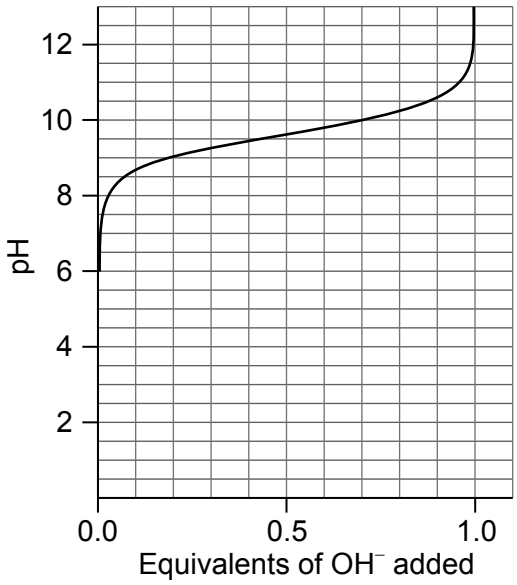
(Option B continues on the following page)

(Option B continued)

15. Analysis of amino acid and protein concentration is a key area of biological research.

The titration curve of aqueous glycine zwitterions with aqueous sodium hydroxide is shown from pH 6.0 to 13.0. Refer to section 33 of the data booklet.



(a) Deduce the pH range in which glycine is an effective buffer in basic solution. [1]

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(Option B continues on the following page)

(Option B, question 15 continued)

(b) Enzymes are biological catalysts.

The data shows the effect of substrate concentration, [S], on the rate, v, of an enzyme-catalysed reaction.

[S] / mmol dm^{-3}	**v / mmol dm^{-3} min^{-1}**
0.0	0.00
0.67	0.40
1.5	0.60
2.0	0.68
4.0	0.78
6.0	0.80
8.0	0.80
10.0	0.80

Determine the value of the Michaelis constant (K_m) from the data. A graph is not required. [1]

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(c) Outline the action of a non-competitive inhibitor on the enzyme-catalysed reaction. [2]

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(Option B continues on the following page)

(Option B, question 15 continued)

(d) The sequence of nitrogenous bases in DNA determines hereditary characteristics.

Calculate the mole percentages of cytosine, guanine and thymine in a double helical DNA structure if it contains 17 % adenine by mole. [2]

Cytosine:

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Guanine:

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Thymine:

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(Option B continues on the following page)

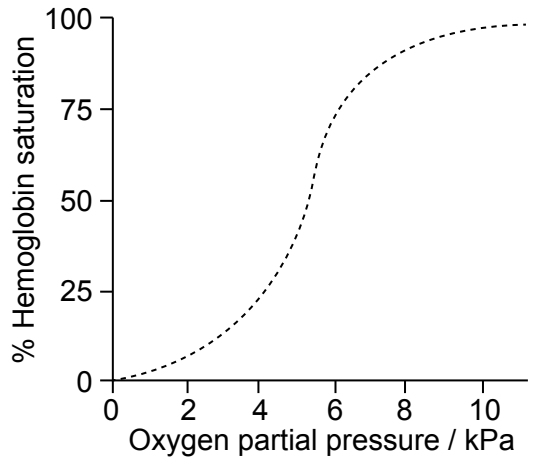
(Option B continued)

16. Biological pigments include a variety of chemical structures with diverse functions.

The graph shows the conversion of hemoglobin to oxyhemoglobin.

$$Hb(aq) + 4O_2(g) \rightleftharpoons Hb(O_2)_4(aq)$$

The partial pressure of oxygen gas, $p(O_2)$ is proportional to its concentration.



(a) Explain the shape of the curve at low oxygen partial pressure up to about 5 kPa. [2]

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(b) (i) Sketch a graph on the axes above to show the effect of decreasing pH on the binding of oxygen to hemoglobin (the Bohr Effect). [1]

(ii) Outline the effect of decreasing pH on the oxygen saturation of hemoglobin. [1]

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(Option B continues on the following page)

(Option B continued)

17. Vision is dependent on retinol (vitamin A) present in retina cells. Retinol is oxidized to the photosensitive chemical 11-*cis*-retinal and isomerizes to 11-*trans*-retinal on absorption of light.

Outline how the formation of 11-*trans*-retinal results in the generation of nerve signals to the brain. [2]

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End of Option B

Option C — Energy

18. Carbon is produced by fusion reactions in stars.

(a) Outline how the spectra of light from stars can be used to detect the presence of carbon. [1]

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(b) The main fusion reaction responsible for the production of carbon is:

$$\mathbf{X} + {}^{4}_{2}\mathrm{He} \rightarrow {}^{12}_{6}\mathrm{C}$$

(i) Deduce the identity of **X**. [1]

. . . . . .

(ii) The mass of **X** is 8.005305 amu and that of ${}^{4}_{2}\mathrm{He}$ is 4.002603 amu. Determine the energy produced, in J, when one atom of ${}^{12}_{6}\mathrm{C}$ is formed in this reaction. Use section 2 of the data booklet. [3]

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(c) Nuclear fusion reactors are predicted to become an important source of electrical energy in the future. State **two** advantages of nuclear fusion over nuclear fission. [2]

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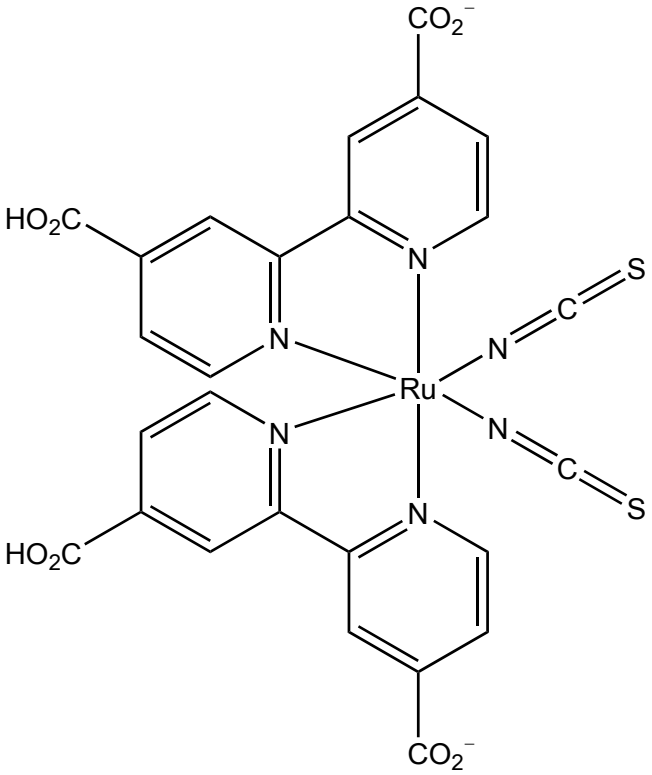
(Option C continues on the following page)

(Option C continued)

19. Dye-Sensitized Solar Cells (DSSCs) use organic dyes. Their interaction with light has some similarities to photosynthesis.



[Source: www.google.com/patents]

(a) Identify **two** ways in which the structure of the dye shown resembles the chlorophyll molecule. Use section 35 of the data booklet. [2]

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(b) Both photosynthesis and the Grätzel cell use energy from sunlight to bring about reduction. Deduce an equation for the reduction reaction in the electrolyte of a Grätzel cell. [1]

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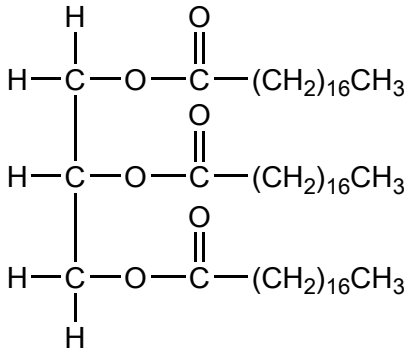
(Option C continues on the following page)

(Option C continued)

20. Vegetable oils, such as that shown, require conversion to biodiesel for use in current internal combustion engines.



(a) State **two** reagents required to convert vegetable oil to biodiesel. [2]

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(b) Deduce the formula of the biodiesel formed when the vegetable oil shown is reacted with the reagents in (a). [1]

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(Option C continues on the following page)

(Option C, question 20 continued)

(c) Determine the specific energy, in $kJ\,g^{-1}$, and energy density, in $kJ\,cm^{-3}$, of a particular biodiesel using the following data and section 1 of the data booklet.

Density = $0.850\,g\,cm^{-3}$; Molar mass = $299\,g\,mol^{-1}$;
Enthalpy of combustion = $12.0\,MJ\,mol^{-1}$. [2]

Specific energy:

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Energy density:

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21. Coal is often converted to liquid hydrocarbon fuels through initial conversion to carbon monoxide and hydrogen.

(a) State how these gases are produced, giving the appropriate equation(s). [2]

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(b) Outline how the carbon monoxide is then converted to a hydrocarbon fuel. [1]

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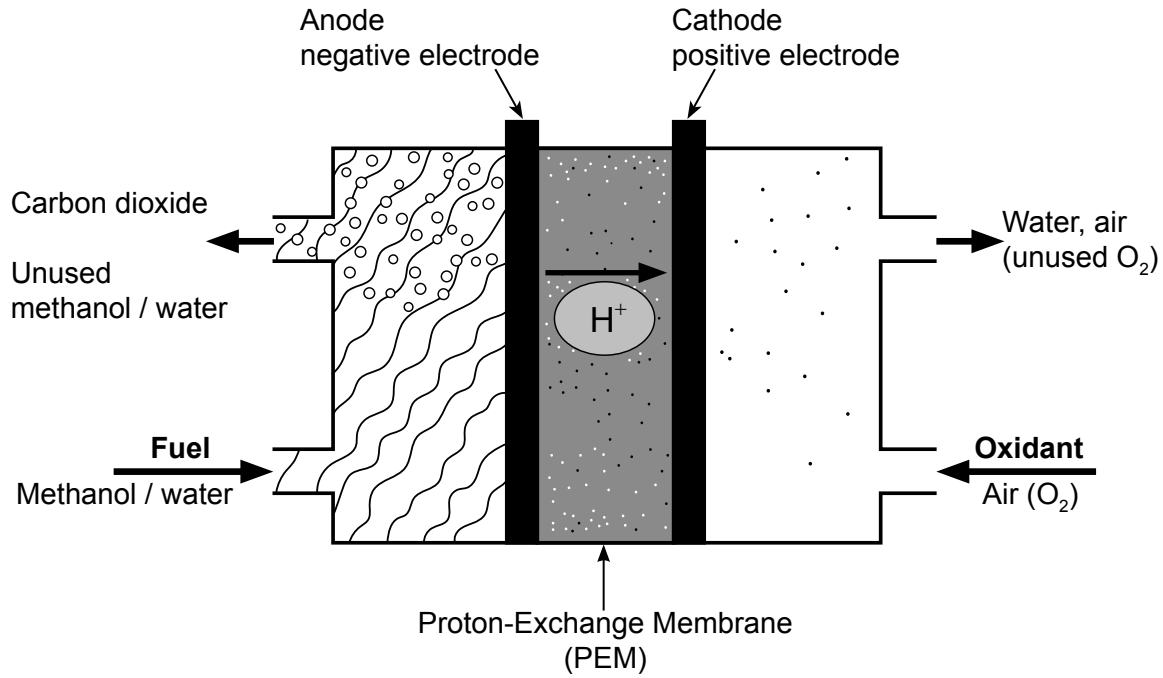
(Option C continues on the following page)

(Option C continued)

22. As well as being burnt, methanol can also be used to provide electricity through a fuel cell. A schematic diagram of such a fuel cell, that depends on the transfer of hydrogen ions between the electrodes, is shown below.



[Source: adapted from http://greenbigtruck.com]

(a) Deduce half-equations for the reactions at the two electrodes and hence the equation for the overall reaction. [3]

Anode (negative electrode):

. . . . . .

Cathode (positive electrode):

. . . . . .

Overall:

. . . . . .

(Option C continues on the following page)

(Option C, question 22 continued)

(b) Even though fuel cells, primary cells and rechargeable cells have similar fundamental characteristics, there are important differences between them.

(i) Suggest a way in which they are similar. [1]

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(ii) Outline the difference between primary and rechargeable cells. [1]

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(c) Identify **one** factor that affects the voltage of a cell and **a different factor** that affects the current it can deliver. [2]

Voltage:

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Current:

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23. A link between the combustion of fossil fuels and an increase in the temperature of the Earth's atmosphere was proposed over a century ago.

(a) Suggest why it is only in recent years that specific predictions of the future effects of fossil fuel combustion have been made. [1]

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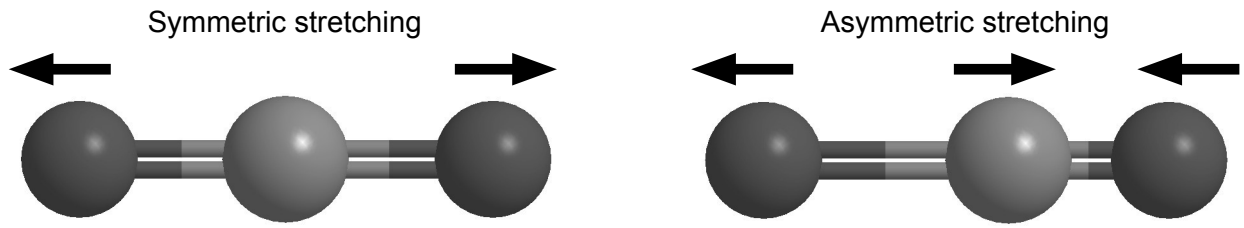
(Option C continues on the following page)

(Option C, question 23 continued)

(b) Carbon dioxide has two different bond stretching modes illustrated below.



Predict, with an explanation, whether these stretching modes will absorb infrared radiation. [2]

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(c) Outline, giving the appropriate equation(s), how increasing levels of carbon dioxide will affect the pH of the oceans. [1]

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(d) Many combustion processes also release particulate matter into the atmosphere. Suggest, giving your reason, how this might affect the temperature of the Earth's surface. [1]

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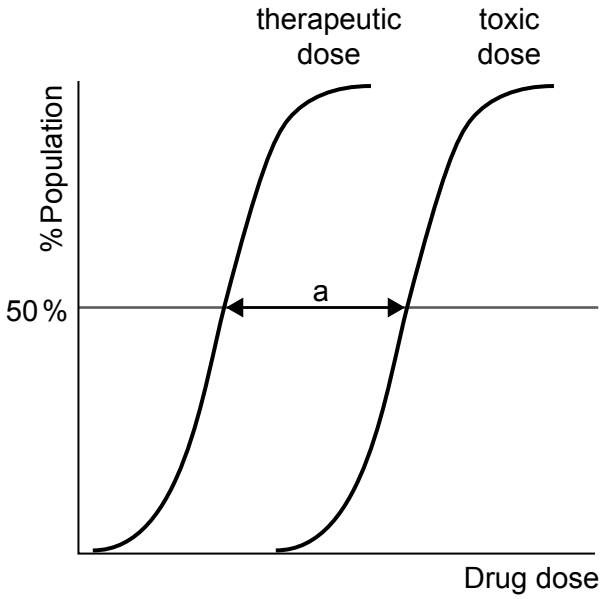
End of Option C

Option D — Medicinal chemistry

24. Medicines have a variety of different effects on the body and act at the molecular level.

(a) Dose response curves are determined for each drug.



Outline the significance of range “a”. [1]

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. . . . . .

(b) State and explain the action of opiates as painkillers. [2]

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(Option D continues on the following page)

(Option D continued)

25. Solubility plays an important role in the bioavailability of drugs in the body.

(a) Suggest why aspirin is **slightly** soluble in water. Refer to section 37 of the data booklet. [2]

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(b) A student prepares aspirin from salicylic acid in the laboratory, extracts it from the reaction mixture, ensures the sample is dry and determines its melting point.

Substance	Melting point / °C
Student's aspirin sample	120–126
Pure aspirin	136

Suggest why the melting point of the student's sample is lower and not sharp compared to that of pure aspirin. [2]

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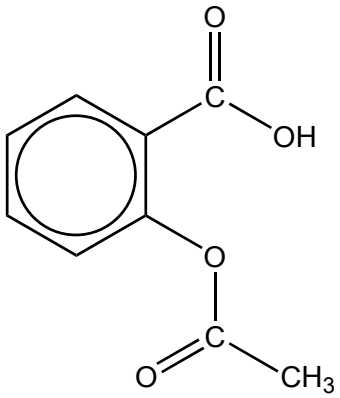
(Option D continues on the following page)

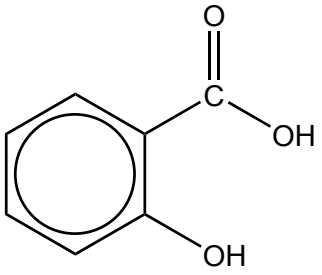
(Option D, question 25 continued)

(c) Organic molecules can be characterized using infrared (IR) spectroscopy.

Compare and contrast the infrared peaks above 1500 cm^{-1} in pure samples of aspirin and salicylic acid using section 26 of the data booklet. [2]



aspirin



salicylic acid

One similarity:

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. . . . . .

One difference:

. . . . . .

. . . . . .

(d) Some mild analgesics contain a solid mixture of acidic aspirin and a non-acidic organic chemical of similar polarity to asprin.

Discuss how acid-base properties and the process of solvent extraction can be used to separate aspirin from the mixture. [3]

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(Option D continues on the following page)

(Option D, question 25 continued)

(e) The pharmaceutical industry is one of the largest producers of waste solvents.

State a green solution to the problem of organic solvent waste. [1]

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26. The buffer formed by carbon dioxide, $CO_2(aq)$ and hydrogen carbonate ion, $HCO_3^-(aq)$, plays an important role in maintaining the pH of blood.

(a) Calculate the pH of the buffer from the following data and section 1 of the data booklet.

$pK_a(CO_2) = 6.34$ [1]
$[HCO_3^-(aq)] = 1.40 \times 10^{-2}\,mol\,dm^{-3}$
$[CO_2(aq)] = 1.25 \times 10^{-3}\,mol\,dm^{-3}$

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(b) Explain the effect of a large amount of aspirin on the pH of blood. [2]

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(Option D continues on the following page)

(Option D continued)

27. Antiviral drugs are designed to take different approaches to fighting viruses.

(a) Outline how oseltamivir (Tamiflu®) works. [2]

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(b) Oseltamivir was commercially produced from shikimic acid, a precursor which is a metabolite in micro-organisms and plants.

Outline how green chemistry was used to develop the precursor for oseltamivir in order to overcome a shortage of the drug during the flu season. [2]

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(c) Suggest why the administration of antibiotics to humans and animals can affect the environment. [1]

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(Option D continues on the following page)

(Option D continued)

28. A polarimeter can be used to determine the optical rotation of an optically active substance.

(a) Describe what happens to plane-polarized light when it passes through a solution of an optically active compound. [1]

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(b) A mixture of enantiomers shows optical rotation.

Suggest a conclusion you can draw from this data. [1]

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29. Nuclear radiation is dangerous because of its ability to damage cells but it can also be used in nuclear medicine.

(a) Yttrium-90 is used in treating certain cancers.

Formulate a nuclear equation for the beta decay of yttrium-90. [1]

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(b) Lutetium-177 is a common isotope used for internal radiation therapy.

Suggest why lutetium-177 is an ideal isotope for the treatment of certain cancers based on the type of radiation emitted. [1]

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(Option D continues on the following page)

(Option D, question 29 continued)

(c) Iodine-131 is released in nuclear explosions but is used in scanners for thyroid cancer. The half-life of iodine-131 is 8.02 days.

(i) Calculate the rate constant, λ, in day^{-1}, for the decay of iodine-131 using section 1 of the data booklet. [1]

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(ii) Calculate the time, in days, for 90 % of the sample to decay. [2]

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(d) A breathalyser measures the blood alcohol content from a breath sample. Formulate half-equations for the reactions at the anode (negative electrode) and the cathode (positive electrode) in a fuel cell breathalyser. [2]

Anode (negative electrode):

. . . . . .

Cathode (positive electrode):

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End of Option D

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