



Victorian Certificate of Education 2011

SUPERVISOR TO ATTACH PROCESSING LABEL HERE

STUDENT NUMBER

Letter

Figures										
Words										

CHEMISTRY

Written examination 2

Monday 14 November 2011

Reading time: 9.00 am to 9.15 am (15 minutes)

Writing time: 9.15 am to 10.45 am (1 hour 30 minutes)

QUESTION AND ANSWER BOOK

Structure of book

Section	Number of questions	Number of questions to be answered	Number of marks
A	20	20	20
B	8	8	52
			Total 72

- Students are permitted to bring into the examination room: pens, pencils, highlighters, erasers, sharpeners, rulers and one scientific calculator.
- Students are NOT permitted to bring into the examination room: blank sheets of paper and/or white out liquid/tape.

Materials supplied

- Question and answer book of 25 pages.
- A data book.
- Answer sheet for multiple-choice questions.

Instructions

- Write your **student number** in the space provided above on this page.
- Check that your **name** and **student number** as printed on your answer sheet for multiple-choice questions are correct, **and** sign your name in the space provided to verify this.
- All written responses must be in English.

At the end of the examination

- Place the answer sheet for multiple-choice questions inside the front cover of this book.
- You may keep the data book.

Students are NOT permitted to bring mobile phones and/or any other unauthorised electronic devices into the examination room.

SECTION A – Multiple-choice questions

Instructions for Section A

Answer **all** questions in pencil on the answer sheet provided for multiple-choice questions.

Choose the response that is **correct** or that **best answers** the question.

A correct answer scores 1, an incorrect answer scores 0.

Marks will **not** be deducted for incorrect answers.

No marks will be given if more than one answer is completed for any question.

Question 1

Consider the following equilibrium expression.

$$K = \frac{[L][M]^4}{[J]^6 [K]}$$

The equation of the forward reaction for this equilibrium expression is

- A. $6J + K \rightleftharpoons L + 4M$
 B. $L + M_4 \rightleftharpoons J_6 + K$
 C. $J_6 + K \rightleftharpoons L + M_4$
 D. $L + 4M \rightleftharpoons 6J + K$

Question 2

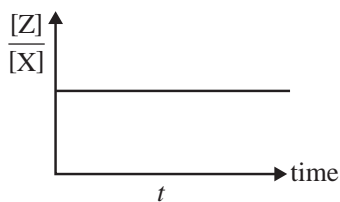
Consider the following equilibrium.



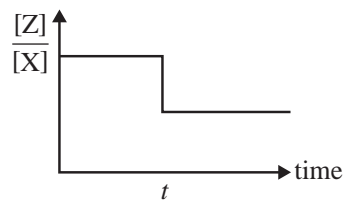
A catalyst is added to the equilibrium mixture at time t . The temperature and volume of the mixture remain constant.

Which one of the following graphs best represents the change in the equilibrium ratio $\frac{[Z]}{[X]}$?

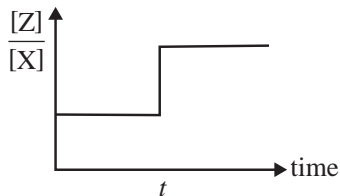
A.



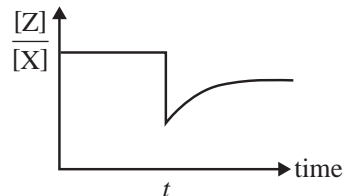
B.



C.



D.

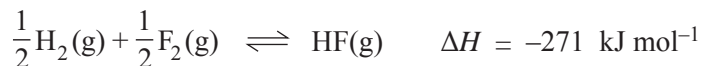


SECTION A – continued

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Use the following information to answer Questions 3 and 4.

Hydrogen and fluorine react according to the following equation.



In an experiment, 0.250 mol of hydrogen and 0.340 mol of fluorine were placed in a reaction vessel that had a volume of V litres. Once equilibrium was established, there was 0.220 mol of HF present in the reaction vessel.

Question 3

Which one of the following expressions can be used to calculate the value of the equilibrium constant for this reaction?

- A. $\frac{[\text{HF}]}{\frac{1}{2}[\text{H}_2] + \frac{1}{2}[\text{F}_2]}$
- B. $\frac{[\text{HF}]}{[\text{H}_2][\text{F}_2]}$
- C. $\frac{n(\text{HF})}{n(\text{H}_2) \times n(\text{F}_2)}$
- D. $\frac{n(\text{HF})}{n(\text{H}_2)^{\frac{1}{2}} \times n(\text{F}_2)^{\frac{1}{2}}}$

Question 4

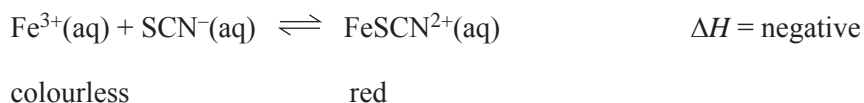
The reaction vessel is surrounded by a heat exchanger that keeps the reaction mixture at a constant temperature.

The amount of heat energy absorbed by the heat exchanger in order to keep a constant temperature in the reaction vessel is

- A. 24.4 kJ
- B. 59.6 kJ
- C. 67.8 kJ
- D. 92.1 kJ

Question 5

It is proposed to indirectly determine the concentration of Fe^{3+} ions in a solution by using UV-visible spectroscopy to measure the concentration of red-coloured FeSCN^{2+} ions generated by the equilibrium reaction



This procedure would provide the **most** accurate estimate of the concentration of Fe^{3+} ions in the original solution if

- A. the value of the equilibrium constant is small, an excess of SCN^{-} is used, and the analysis is carried out at a low temperature.
- B. the value of the equilibrium constant is large, an excess of Fe^{3+} is used, and the analysis is carried out at a high temperature.
- C. the value of the equilibrium constant is small, an excess of Fe^{3+} is used, and the analysis is carried out at a high temperature.
- D. the value of the equilibrium constant is large, an excess of SCN^{-} is used, and the analysis is carried out at a low temperature.

SECTION A – continued
TURN OVER

Question 6

In an endothermic reaction the

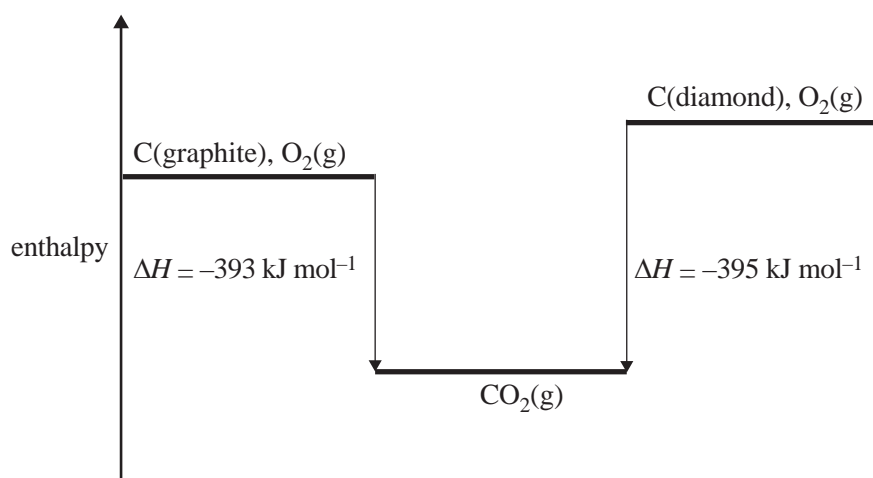
- A. reaction system loses energy to the surroundings.
- B. addition of a catalyst increases the activation energy.
- C. activation energy is greater than the enthalpy of reaction.
- D. energy required to break bonds in the reactants is less than the energy released when bonds are formed in the products.

Question 7

Consider the following combustion reactions for graphite and diamond.



The following diagram summarises this information.



From the data provided it can be determined that the enthalpy change, ΔH , for the conversion of graphite to diamond



is

- A. -2 kJ mol^{-1}
- B. $+2 \text{ kJ mol}^{-1}$
- C. -788 kJ mol^{-1}
- D. $+788 \text{ kJ mol}^{-1}$

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SECTION A – continued

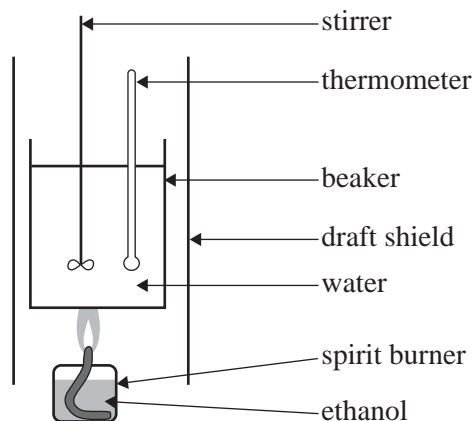
Question 8

What mass of butane ($M = 58.0 \text{ g mol}^{-1}$) must undergo complete combustion to raise the temperature of 100.0 g of water by $1.00 \text{ }^\circ\text{C}$? Assume that there is no heat loss.

- A. 8.44 g
- B. 6.88 g
- C. 0.399 g
- D. $8.44 \times 10^{-3} \text{ g}$

Question 9

A student experimentally determined the molar enthalpy of combustion of ethanol ($M = 46.0 \text{ g mol}^{-1}$) using the equipment shown in the following simplified diagram.



The student made the following experimental measurements.

Mass of water in beaker	=	100.0 g
Amount of ethanol combusted	=	0.0200 mol
Temperature rise of the water	=	$40.0 \text{ }^\circ\text{C}$

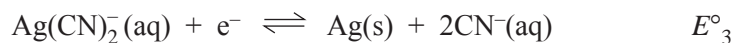
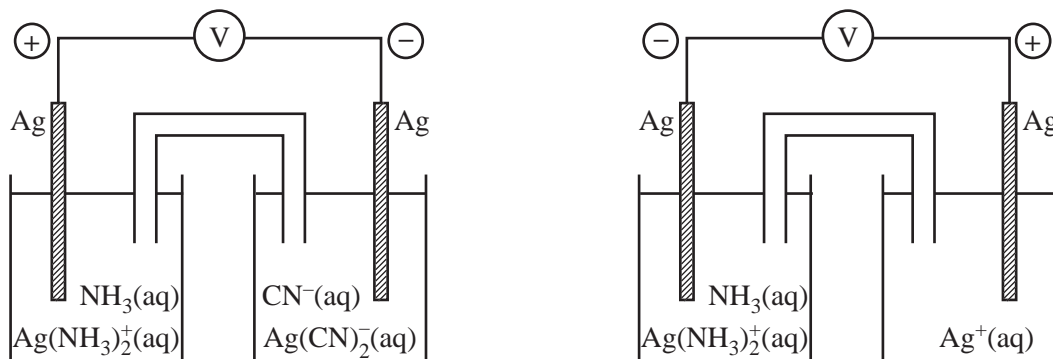
The molar enthalpy of combustion of ethanol calculated from the student's results is

- A. $-16.7 \text{ kJ mol}^{-1}$
- B. $-18.2 \text{ kJ mol}^{-1}$
- C. -334 kJ mol^{-1}
- D. -836 kJ mol^{-1}

SECTION A – continued
TURN OVER

Question 10

Two galvanic cells were constructed under standard conditions in an experiment to determine the relative positions in the electrochemical series of the standard electrode potential, E° , for the following reactions. Both cells generate a potential difference.



The values of the electrode potentials in order from highest to lowest would be

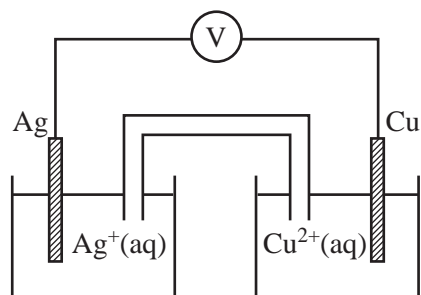
- A. $E^\circ_1, E^\circ_2, E^\circ_3$
 B. $E^\circ_1, E^\circ_3, E^\circ_2$
 C. $E^\circ_2, E^\circ_1, E^\circ_3$
 D. $E^\circ_3, E^\circ_2, E^\circ_1$

NO WRITING ALLOWED IN THIS AREA

SECTION A – continued

Use the following information to answer Questions 11 and 12.

The following galvanic cell was set up under standard conditions.



Question 11

The overall equation for the reaction occurring in this galvanic cell is

- A. $\text{Ag}^+(\text{aq}) + \text{Cu}(\text{s}) \rightarrow \text{Ag}(\text{s}) + \text{Cu}^{2+}(\text{aq})$
- B. $\text{Ag}(\text{s}) + \text{Cu}^{2+}(\text{aq}) \rightarrow \text{Ag}^+(\text{aq}) + \text{Cu}(\text{s})$
- C. $2\text{Ag}^+(\text{aq}) + \text{Cu}(\text{s}) \rightarrow 2\text{Ag}(\text{s}) + \text{Cu}^{2+}(\text{aq})$
- D. $2\text{Ag}(\text{s}) + \text{Cu}^{2+}(\text{aq}) \rightarrow 2\text{Ag}^+(\text{aq}) + \text{Cu}(\text{s})$

Question 12

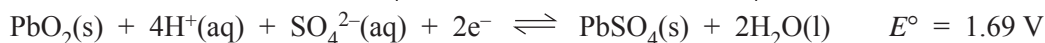
The predicted maximum voltage produced by this cell under standard conditions is

- A. 0.46 V
- B. 1.14 V
- C. 1.26 V
- D. 1.94 V

SECTION A – continued
TURN OVER

Use the following information to answer Questions 13–16.

The lead-acid battery is made up of a series of secondary cells in which the following half-reactions are utilised.



Question 13

When the battery is discharging the

- A. H^+ concentration decreases resulting in a higher pH.
- B. H^+ concentration increases resulting in a higher pH.
- C. H^+ concentration decreases resulting in a lower pH.
- D. H^+ concentration increases resulting in a lower pH.

Question 14

When the lead-acid battery is recharging the energy transformation occurring is

- A. chemical \rightarrow electrical + heat.
- B. kinetic \rightarrow chemical + electrical + heat.
- C. electrical \rightarrow chemical + heat.
- D. electrical \rightarrow light + kinetic + heat.

Question 15

The reaction which occurs at the anode when the battery is recharging is

- A. $\text{PbSO}_4(\text{s}) + 2\text{e}^- \rightarrow \text{Pb}(\text{s}) + \text{SO}_4^{2-}(\text{aq})$
- B. $\text{Pb}(\text{s}) + \text{SO}_4^{2-}(\text{aq}) \rightarrow \text{PbSO}_4(\text{s}) + 2\text{e}^-$
- C. $\text{PbSO}_4(\text{s}) + 2\text{H}_2\text{O}(\text{l}) \rightarrow \text{PbO}_2(\text{s}) + 4\text{H}^+(\text{aq}) + \text{SO}_4^{2-}(\text{aq}) + 2\text{e}^-$
- D. $\text{PbO}_2(\text{s}) + 4\text{H}^+(\text{aq}) + \text{SO}_4^{2-}(\text{aq}) + 2\text{e}^- \rightarrow \text{PbSO}_4(\text{s}) + 2\text{H}_2\text{O}(\text{l})$

Question 16

When recharging the lead-acid battery the positive terminal of the power supply should be connected to the

- A. positive terminal of the battery where oxidation will occur.
- B. positive terminal of the battery where reduction will occur.
- C. negative terminal of the battery where oxidation will occur.
- D. negative terminal of the battery where reduction will occur.

Question 17

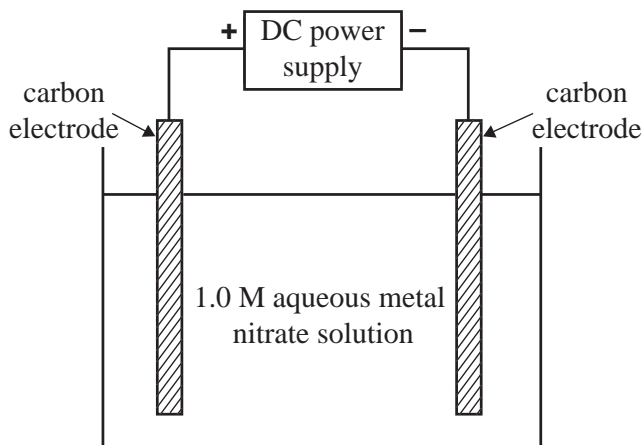
If we compare a galvanic cell with an electrolytic cell, it is true to state that

- A. in a galvanic cell reduction occurs at the negative electrode.
- B. in both cells the anode is positive and the cathode is negative.
- C. in an electrolytic cell oxidation occurs at the cathode.
- D. in both cells reduction occurs at the cathode.

NO WRITING ALLOWED IN THIS AREA

Question 18

A series of electrolysis experiments is conducted using the apparatus shown below.



An electric charge of 0.030 faraday was passed through separate solutions of 1.0 M $\text{Cr}(\text{NO}_3)_3$, 1.0 M $\text{Cu}(\text{NO}_3)_2$ and 1.0 M AgNO_3 . In each case the corresponding metal was deposited on the negative electrode. The amount, in mol, of each metal deposited is

	Amount, in mol, of chromium deposited	Amount, in mol, of copper deposited	Amount, in mol, of silver deposited
A.	0.030	0.030	0.030
B.	0.010	0.015	0.030
C.	0.090	0.060	0.030
D.	0.030	0.020	0.010

Question 19

An ornament was coated with a metal, M, by electrolysis of a solution of the metal ion, M^{x+} . During the electrolysis, a current of 1.50 amperes was applied for 180 seconds. The ornament was coated in 0.0014 mol of metal.

The value of x in M^{x+} is

- A. 1
- B. 2
- C. 3
- D. 4

Question 20

Which 0.1 M solution of the following acids has the highest pH?

- A. nitrous acid
- B. ethanoic acid
- C. methanoic acid
- D. hypobromous acid

**END OF SECTION A
TURN OVER**

SECTION B – Short answer questions**Instructions for Section B**

Answer **all** questions in the spaces provided. Write using black or blue pen.

To obtain full marks for your responses you should

- give simplified answers with an appropriate number of significant figures to all numerical questions; unsimplified answers will not be given full marks.
- show all working in your answers to numerical questions. No marks will be given for an incorrect answer unless it is accompanied by details of the working.
- make sure chemical equations are balanced and that the formulas for individual substances include an indication of state; for example, $\text{H}_2(\text{g})$; $\text{NaCl}(\text{s})$

Question 1

During this semester you have studied the production, properties and uses of one of the following industrial chemicals. Circle the chemical you have studied this semester.

ammonia ethene nitric acid sulfuric acid

- a. A Material Safety Data Sheet (MSDS) gives risk and safety phrases that are applicable to a specific chemical.

For example: the MSDS for calcium carbide includes

- the risk phrase, ‘Contact with water liberates an extremely flammable gas’
- the safety phrase ‘Keep the container dry’.

- i. From the list of risk phrases provided below, circle **one** that is applicable to your selected industrial chemical.

Flammable

Toxic by inhalation

Toxic in contact with skin

Toxic if swallowed

Causes burns

Irritating to eyes

Irritating to respiratory system

Irritating to skin

Risk of serious damage to the eyes

Vapours may cause drowsiness and dizziness

- ii. Write a safety phrase that is appropriate for the risk phrase you have identified in **part a. i.**

1 + 1 = 2 marks

NO WRITING ALLOWED IN THIS AREA

SECTION B – Question 1 – continued

- b.** The industrial chemical you have studied is used to make other useful chemicals.
- i.** Identify one useful industrial chemical that is produced from the chemical you have circled on page 10.
-
- ii.** Write an equation for the formation of this useful chemical identified in **part b. i.** You must include your selected industrial chemical as a reactant in this equation.
-
-

1 + 2 = 3 marks

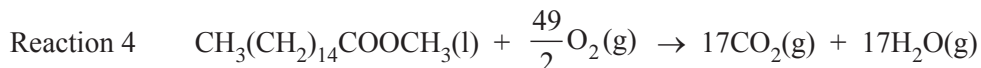
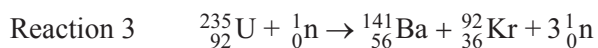
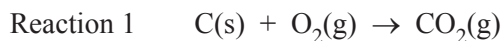
Total 5 marks

SECTION B – continued
TURN OVER

Question 2

Energy resources utilised by society often involve a reaction that produces large amounts of heat. This heat energy can be transformed into another form of energy that is useful to society.

Consider the following list of equations. Each equation represents a reaction that takes place when a fuel is used to generate heat energy.



Select **one** of these reactions and answer the following questions.

Indicate your selection by circling **one** of the following.

Reaction 1

Reaction 2

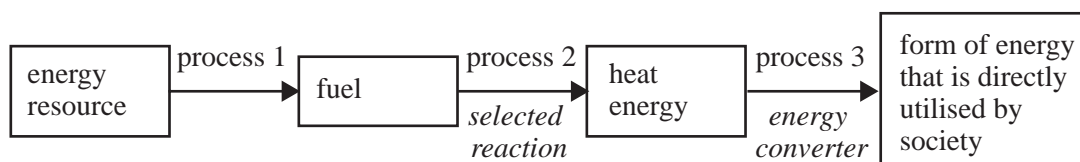
Reaction 3

Reaction 4

- a. i. Identify an energy resource that provides the fuel used in your selected reaction.

- ii. Describe the major difference between a renewable energy resource and a nonrenewable energy resource.

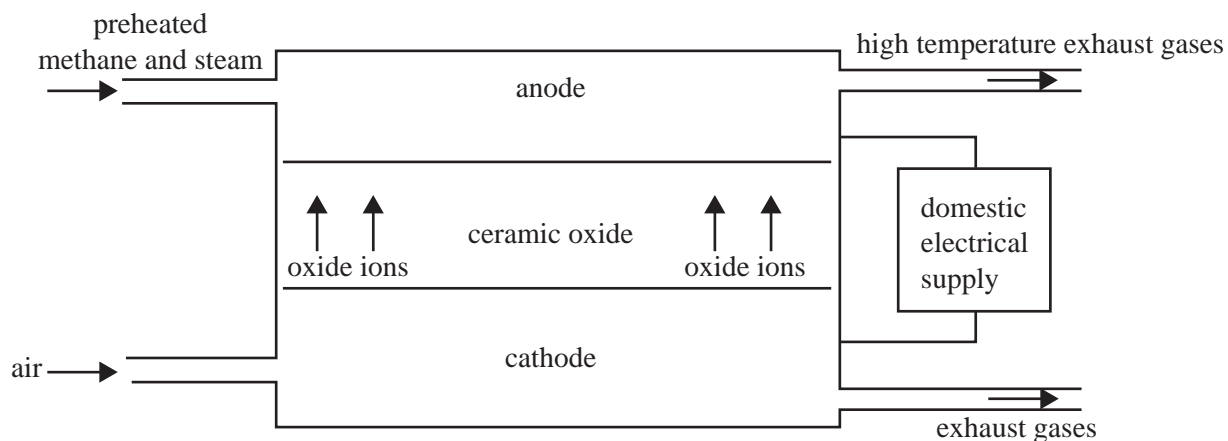
- iii. Consider the following simplified flow chart.



During process 3, heat energy from your selected fuel source is converted into another form of energy that is useful to society. Identify this form of energy and provide one example that describes how this form of energy is used in society.

1 + 1 + 2 = 4 marks

- b. A Victorian company produces solid oxide fuel cells for use in the home. These fuel cells use natural gas to produce electricity through an electrochemical process summarised in the diagram below.



- i. Suggest one way in which a fuel cell differs from other galvanic cells.

- ii. Write an equation for the reaction at the cathode where atmospheric oxygen is converted to oxide ions.

- iii. A complex series of reactions takes place at the anode. These may be summarised by the half-equation



Write an equation that represents the overall reaction that takes place in this fuel cell.

1 + 1 + 1 = 3 marks

Total 7 marks

SECTION B – continued
TURN OVER

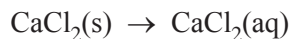
Question 3

A solution calorimeter was calibrated by passing an electric current through the heating coil at a potential difference of 5.10 volts. This caused the water in the calorimeter to increase in temperature by 9.50 °C. The calibration factor for this calorimeter was previously determined to be 0.354 kJ °C⁻¹.

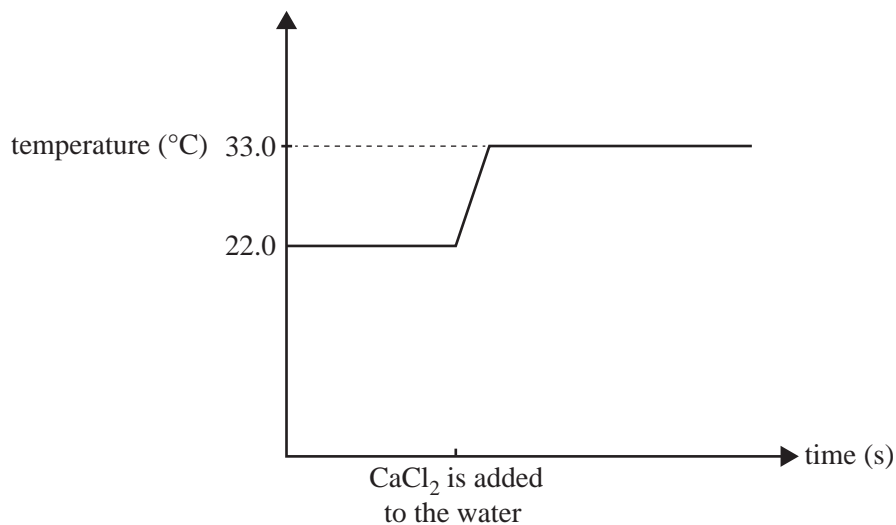
- a. Use the calibration factor to determine the electrical charge, in coulombs, that passed through the heating coil.

2 marks

This calorimeter is then used to determine the enthalpy change for the dissolution of one mol of anhydrous calcium chloride, CaCl₂, in water.



6.038 g of solid anhydrous calcium chloride, CaCl₂, was added to the water. The mixture was stirred until all the solid had dissolved. The temperature was monitored before and after the addition of the calcium chloride. The results are shown in the graph below.



- b. i. Is this reaction exothermic or endothermic?
Explain your answer.

SECTION B – Question 3 – continued

- ii. Use the calibration factor to calculate the enthalpy change for the dissolution of 1.00 mol of $\text{CaCl}_2(\text{s})$. The molar mass of $\text{CaCl}_2 = 111.1 \text{ g mol}^{-1}$.

2 + 4 = 6 marks

Total 8 marks

SECTION B – continued
TURN OVER

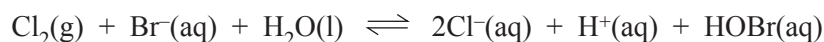
NO WRITING ALLOWED IN THIS AREA

Question 4

- a. This question requires you to refer to the Data Book and the information in the table below.

	Standard electrode potential E° in volts
$\text{HOBr(aq)} + \text{H}^+(\text{aq}) + 2\text{e}^- \rightleftharpoons \text{Br}^-(\text{aq}) + \text{H}_2\text{O(l)}$	+1.33
$2\text{HOBr(aq)} + 2\text{H}^+(\text{aq}) + 2\text{e}^- \rightleftharpoons \text{Br}_2(\text{l}) + 2\text{H}_2\text{O(l)}$	+1.60

Explain why the following reaction between chlorine gas and bromide ions is **not** predicted to occur to any significant extent under standard conditions.



2 marks

- b. Chlorine can be manufactured in the laboratory by reacting concentrated hydrochloric acid with solid manganese(IV) oxide.



Write the oxidation half-equation for this reaction.

1 mark

Total 3 marks

NO WRITING ALLOWED IN THIS AREA

SECTION B – continued

NO WRITING ALLOWED IN THIS AREA

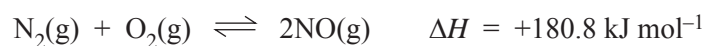
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**SECTION B – continued
TURN OVER**

Question 5

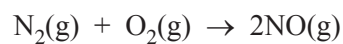
Nitrogen oxides are commonly found in the atmosphere in areas where there is serious atmospheric pollution.

Nitrogen monoxide, NO, is generated from the reaction between nitrogen and oxygen.



- a. A sealed container is filled with 1.00 mole of NO(g) and equilibrium is established. The temperature is maintained at 1500 °C.

Explain why the rate of the reaction



will never be greater than the rate of the reaction



- i. while the system is reaching equilibrium

- ii. once equilibrium is established.

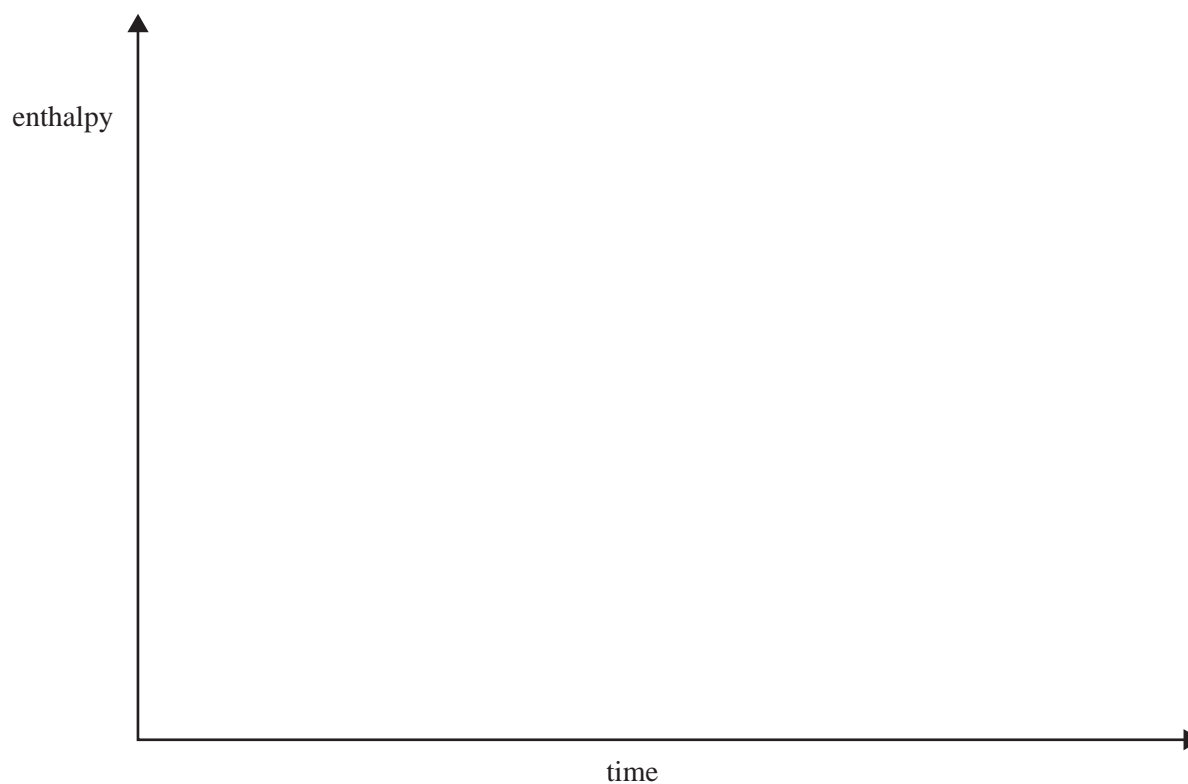
1 + 1 = 2 marks

NO WRITING ALLOWED IN THIS AREA

SECTION B – Question 5 – continued

- b.** NO(g) is produced in combustion engines such as a car engine. Catalysts based on platinum and palladium are used in the exhaust system to decompose NO(g) into N₂(g) and O₂(g).
- i.** Based on the information provided, explain why combustion engines are such good chemical environments for the production of NO(g).

- ii.** Sketch, on the axes provided below, a fully labelled energy profile diagram for the decomposition reaction of NO. Indicate on the diagram the effect of using a catalyst in this reaction.



2 + 3 = 5 marks

Total 7 marks

SECTION B – continued
TURN OVER

NO WRITING ALLOWED IN THIS AREA

Question 6

- a. i. Write an equation for the reaction of methanoic acid with water.

- ii. Write an equilibrium expression for the acidity constant, K_a , for the reaction in **part i**.

1 + 1 = 2 marks

- b. A solution is prepared by adding 0.500 mol of methanoic acid, HCOOH, and 0.100 mol of sodium methanoate, HCOONa, to 2.00 L of water.

- i. Determine the concentration of H_3O^+ ions in this solution.

In your calculations assume that

- the equilibrium concentration of HCOOH is approximately equal to the initial concentration of HCOOH
- the equilibrium concentration of $HCOO^-$ is approximately equal to the initial concentration of $HCOO^-$

- ii. Calculate the pH of this solution.

NO WRITING ALLOWED IN THIS AREA

SECTION B – Question 6 – continued

iii. The following two solutions are prepared.

- Solution A: 1.00 L solution contains 0.500 mole of methanoic acid.
- Solution B: 1.00 L solution contains 0.500 mole of methanoic acid and 0.100 mole of sodium methanoate.

Which solution has the higher pH? Justify your answer in terms of the equilibria involved.

3 + 1 + 2 = 6 marks

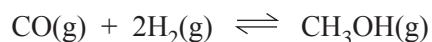
Total 8 marks

SECTION B – continued
TURN OVER

Question 7

Methanol is produced on an industrial scale by the catalytic conversion of a mixture of hydrogen and carbon monoxide gases at a temperature of 520 K and a pressure of 50 to 100 atmospheres.

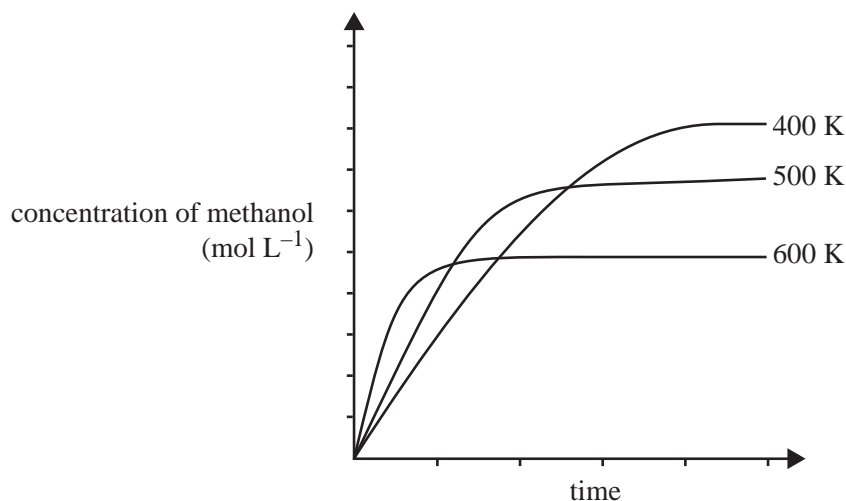
The reaction that occurs in the methanol converter is



- a. Carbon monoxide gas and hydrogen gas are mixed in a reaction vessel and equilibrium is established.

The graph below shows how the concentration of methanol in this vessel changes with time at three different temperatures.

The pressure is the same at each temperature.



- i. Is the reaction exothermic or endothermic?

Explain your answer.

- ii. Explain why a moderately high temperature of 520 K is used although the equilibrium concentration of methanol is greater at a lower temperature.

SECTION B – Question 7 – continued

- iii. Explain why, at a given temperature, the use of high pressures results in a greater equilibrium concentration of methanol.

2 + 1 + 2 = 5 marks

- b. A catalyst consisting of a mixture of copper, zinc and aluminium is used to increase the rate of this reaction. Explain how a catalyst can increase reaction rate.

1 mark

Total 6 marks

SECTION B – continued
TURN OVER

Question 8

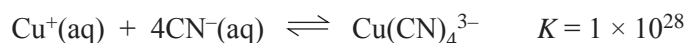
A chemical engineer designs a pilot plant to determine the conditions that will give the best results for copper plating different objects.

A range of experiments indicates that an electroplating cell with an aqueous electrolyte containing copper(I) cyanide, CuCN, potassium cyanide, KCN, and potassium hydroxide, KOH, will produce a uniform copper coating.

- a. Write a balanced half-equation for the cathode reaction in this electrolytic cell.

1 mark

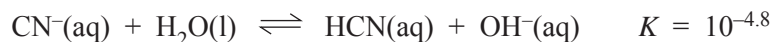
The quality of the copper coating depends on maintaining a low, constant concentration of copper(I) ions in the electrolyte. This is achieved by making use of the following reaction which takes place in the electrolyte bath. In this reaction, copper(I) ions, Cu⁺, react with the cyanide ions, CN⁻, according to the equation



- b. Refer to this information to explain how the presence of excess potassium cyanide in the electrolyte maintains a low concentration of Cu⁺(aq) ions in solution.

1 mark

The cyanide ion, CN⁻, is the conjugate base of the acid hydrogen cyanide, HCN.



Hydrogen cyanide is highly toxic and can bubble out of solution.

- c. Explain how the presence of potassium hydroxide in the electrolyte is essential to the safe operation of this cell.

1 mark

Any gas produced at the cathode is found to damage the quality of the copper plate. This is avoided by maintaining a low current.

- d. Write a balanced equation for the gas most likely to be produced at the cathode if the current is too high.

1 mark

SECTION B – Question 8 – continued



**Victorian Certificate of Education
2011**

CHEMISTRY
Written examination

Monday 14 November 2011

Reading time: 9.00 am to 9.15 am (15 minutes)

Writing time: 9.15 am to 10.45 am (1 hour 30 minutes)

DATA BOOK

Directions to students

- A question and answer book is provided with this data book.

Students are NOT permitted to bring mobile phones and/or any other unauthorised electronic devices into the examination room.

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1. Periodic table of the elements

1 H 1.0 Hydrogen		4 Be 9.0 Beryllium		79 Au 197.0 Gold		5 B 10.8 Boron		6 C 12.0 Carbon		7 N 14.0 Nitrogen		8 O 16.0 Oxygen		9 F 19.0 Fluorine		2 He 4.0 Helium																																																																																									
3 Li 6.9 Lithium		12 Mg 24.3 Magnesium		atomic number		relative atomic mass		symbol of element		name of element																																																																																															
11 Na 23.0 Sodium	19 K 39.1 Potassium	20 Ca 40.1 Calcium	21 Sc 44.9 Scandium	22 Ti 47.9 Titanium	23 V 50.9 Vanadium	24 Cr 52.0 Chromium	25 Mn 54.9 Manganese	26 Fe 55.9 Iron	27 Co 58.9 Cobalt	28 Ni 58.7 Nickel	29 Cu 63.6 Copper	30 Zn 65.4 Zinc	31 Ga 69.7 Gallium	32 Ge 72.6 Germanium	33 As 74.9 Arsenic	34 Se 79.0 Selenium	35 Br 79.9 Bromine	36 Kr 83.8 Krypton	37 Rb 85.5 Rubidium	38 Sr 87.6 Strontium	39 Y 88.9 Yttrium	40 Zr 91.2 Zirconium	41 Nb 92.9 Niobium	42 Mo 95.9 Molybdenum	43 Tc 98.1 Technetium	44 Ru 101.1 Ruthenium	45 Rh 102.9 Rhodium	46 Pd 106.4 Palladium	47 Ag 107.9 Silver	48 Cd 112.4 Cadmium	49 In 114.8 Indium	50 Sn 118.7 Tin	51 Sb 121.8 Antimony	52 Te 127.6 Tellurium	53 I 126.9 Iodine	54 Xe 131.3 Xenon	55 Cs 132.9 Caesium	56 Ba 137.3 Barium	57 La 138.9 Lanthanum	58 Ac (227) Actinium	59 Pr (227) Praseodymium	60 Nd (262) Neodymium	61 Pm (264) Promethium	62 Sm (266) Samarium	63 Eu (271) Europium	64 Gd (277) Gadolinium	65 Tb (283) Terbium	66 Dy (287) Dysprosium	67 Ho (291) Holmium	68 Er (291) Erbium	69 Tm (291) Thulium	70 Yb (287) Ytterbium	71 Lu (260) Lutetium	87 Fr (223) Francium	88 Ra (226) Radium	89 Ac (227) Actinium	90 Th (232) Thorium	91 Pa (231) Protactinium	92 U (238) Uranium	93 Np (237) Neptunium	94 Pu (244) Plutonium	95 Am (243) Americium	96 Cm (247) Curium	97 Bk (247) Berkelium	98 Cf (251) Californium	99 Es (252) Einsteinium	100 Fm (257) Fermium	101 Md (258) Mendelevium	102 No (259) Nobelium	103 Lr (262) Lawrencium	86 Rn (222) Radon	87 At (210) Astatine	88 Po (209) Polonium	89 Bi (209) Bismuth	90 Pb (207) Lead	91 Tl (204) Thallium	92 Hg (201) Mercury	93 Tl (204) Thallium	94 Pb (207) Lead	95 Bi (209) Bismuth	96 Po (209) Polonium	97 At (210) Astatine	98 Rn (222) Radon	118 Uuo	98 Ce 140.1 Cerium	99 Pr 140.9 Praseodymium	100 Nd 144.2 Neodymium	101 Pm (145) Promethium	102 Sm 150.3 Samarium	103 Eu 152.0 Europium	104 Gd 157.2 Gadolinium	105 Tb 158.9 Terbium	106 Dy 162.5 Dysprosium	107 Ho 164.9 Holmium	108 Er 167.3 Erbium	109 Tm 168.9 Thulium	110 Yb 173.0 Ytterbium	111 Lu 175.0 Lutetium	112 Uub	113 Uuh	114 Uuq	115 Uup	116 Uuq	117 Uuh	118 Uuo
37 Rb 85.5 Rubidium	38 Sr 87.6 Strontium	39 Y 88.9 Yttrium	40 Zr 91.2 Zirconium	41 Nb 92.9 Niobium	42 Mo 95.9 Molybdenum	43 Tc 98.1 Technetium	44 Ru 101.1 Ruthenium	45 Rh 102.9 Rhodium	46 Pd 106.4 Palladium	47 Ag 107.9 Silver	48 Cd 112.4 Cadmium	49 In 114.8 Indium	50 Sn 118.7 Tin	51 Sb 121.8 Antimony	52 Te 127.6 Tellurium	53 I 126.9 Iodine	54 Xe 131.3 Xenon	55 Cs 132.9 Caesium	56 Ba 137.3 Barium	57 La 138.9 Lanthanum	58 Ac (227) Actinium	59 Pr (227) Praseodymium	60 Nd (262) Neodymium	61 Pm (264) Promethium	62 Sm (266) Samarium	63 Eu (271) Europium	64 Gd (277) Gadolinium	65 Tb (283) Terbium	66 Dy (287) Dysprosium	67 Ho (291) Holmium	68 Er (291) Erbium	69 Tm (291) Thulium	70 Yb (287) Ytterbium	71 Lu (260) Lutetium	87 Fr (223) Francium	88 Ra (226) Radium	89 Ac (227) Actinium	90 Th (232) Thorium	91 Pa (231) Protactinium	92 U (238) Uranium	93 Np (237) Neptunium	94 Pu (244) Plutonium	95 Am (243) Americium	96 Cm (247) Curium	97 Bk (247) Berkelium	98 Cf (251) Californium	99 Es (252) Einsteinium	100 Fm (257) Fermium	101 Md (258) Mendelevium	102 No (259) Nobelium	103 Lr (262) Lawrencium	86 Rn (222) Radon	87 At (210) Astatine	88 Po (209) Polonium	89 Bi (209) Bismuth	90 Pb (207) Lead	91 Tl (204) Thallium	92 Hg (201) Mercury	93 Tl (204) Thallium	94 Pb (207) Lead	95 Bi (209) Bismuth	96 Po (209) Polonium	97 At (210) Astatine	98 Rn (222) Radon	118 Uuo	98 Ce 140.1 Cerium	99 Pr 140.9 Praseodymium	100 Nd 144.2 Neodymium	101 Pm (145) Promethium	102 Sm 150.3 Samarium	103 Eu 152.0 Europium	104 Gd 157.2 Gadolinium	105 Tb 158.9 Terbium	106 Dy 162.5 Dysprosium	107 Ho 164.9 Holmium	108 Er 167.3 Erbium	109 Tm 168.9 Thulium	110 Yb 173.0 Ytterbium	111 Lu 175.0 Lutetium	112 Uub	113 Uuh	114 Uuq	115 Uup	116 Uuq	117 Uuh	118 Uuo																			
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2. The electrochemical series

	E° in volt
$\text{F}_2(\text{g}) + 2\text{e}^- \rightleftharpoons 2\text{F}^-(\text{aq})$	+2.87
$\text{H}_2\text{O}_2(\text{aq}) + 2\text{H}^+(\text{aq}) + 2\text{e}^- \rightleftharpoons 2\text{H}_2\text{O}(\text{l})$	+1.77
$\text{Au}^+(\text{aq}) + \text{e}^- \rightleftharpoons \text{Au}(\text{s})$	+1.68
$\text{Cl}_2(\text{g}) + 2\text{e}^- \rightleftharpoons 2\text{Cl}^-(\text{aq})$	+1.36
$\text{O}_2(\text{g}) + 4\text{H}^+(\text{aq}) + 4\text{e}^- \rightleftharpoons 2\text{H}_2\text{O}(\text{l})$	+1.23
$\text{Br}_2(\text{l}) + 2\text{e}^- \rightleftharpoons 2\text{Br}^-(\text{aq})$	+1.09
$\text{Ag}^+(\text{aq}) + \text{e}^- \rightleftharpoons \text{Ag}(\text{s})$	+0.80
$\text{Fe}^{3+}(\text{aq}) + \text{e}^- \rightleftharpoons \text{Fe}^{2+}(\text{aq})$	+0.77
$\text{O}_2(\text{g}) + 2\text{H}^+(\text{aq}) + 2\text{e}^- \rightleftharpoons \text{H}_2\text{O}_2(\text{aq})$	+0.68
$\text{I}_2(\text{s}) + 2\text{e}^- \rightleftharpoons 2\text{I}^-(\text{aq})$	+0.54
$\text{O}_2(\text{g}) + 2\text{H}_2\text{O}(\text{l}) + 4\text{e}^- \rightleftharpoons 4\text{OH}^-(\text{aq})$	+0.40
$\text{Cu}^{2+}(\text{aq}) + 2\text{e}^- \rightleftharpoons \text{Cu}(\text{s})$	+0.34
$\text{Sn}^{4+}(\text{aq}) + 2\text{e}^- \rightleftharpoons \text{Sn}^{2+}(\text{aq})$	+0.15
$\text{S}(\text{s}) + 2\text{H}^+(\text{aq}) + 2\text{e}^- \rightleftharpoons \text{H}_2\text{S}(\text{g})$	+0.14
$2\text{H}^+(\text{aq}) + 2\text{e}^- \rightleftharpoons \text{H}_2(\text{g})$	0.00
$\text{Pb}^{2+}(\text{aq}) + 2\text{e}^- \rightleftharpoons \text{Pb}(\text{s})$	-0.13
$\text{Sn}^{2+}(\text{aq}) + 2\text{e}^- \rightleftharpoons \text{Sn}(\text{s})$	-0.14
$\text{Ni}^{2+}(\text{aq}) + 2\text{e}^- \rightleftharpoons \text{Ni}(\text{s})$	-0.23
$\text{Co}^{2+}(\text{aq}) + 2\text{e}^- \rightleftharpoons \text{Co}(\text{s})$	-0.28
$\text{Fe}^{2+}(\text{aq}) + 2\text{e}^- \rightleftharpoons \text{Fe}(\text{s})$	-0.44
$\text{Zn}^{2+}(\text{aq}) + 2\text{e}^- \rightleftharpoons \text{Zn}(\text{s})$	-0.76
$2\text{H}_2\text{O}(\text{l}) + 2\text{e}^- \rightleftharpoons \text{H}_2(\text{g}) + 2\text{OH}^-(\text{aq})$	-0.83
$\text{Mn}^{2+}(\text{aq}) + 2\text{e}^- \rightleftharpoons \text{Mn}(\text{s})$	-1.03
$\text{Al}^{3+}(\text{aq}) + 3\text{e}^- \rightleftharpoons \text{Al}(\text{s})$	-1.67
$\text{Mg}^{2+}(\text{aq}) + 2\text{e}^- \rightleftharpoons \text{Mg}(\text{s})$	-2.34
$\text{Na}^+(\text{aq}) + \text{e}^- \rightleftharpoons \text{Na}(\text{s})$	-2.71
$\text{Ca}^{2+}(\text{aq}) + 2\text{e}^- \rightleftharpoons \text{Ca}(\text{s})$	-2.87
$\text{K}^+(\text{aq}) + \text{e}^- \rightleftharpoons \text{K}(\text{s})$	-2.93
$\text{Li}^+(\text{aq}) + \text{e}^- \rightleftharpoons \text{Li}(\text{s})$	-3.02

3. Physical constants

Avogadro's constant (N_A) = $6.02 \times 10^{23} \text{ mol}^{-1}$

Charge on one electron = $-1.60 \times 10^{-19} \text{ C}$

Faraday constant (F) = $96\,500 \text{ C mol}^{-1}$

Gas constant (R) = $8.31 \text{ J K}^{-1} \text{ mol}^{-1}$

Ionic product for water (K_w) = $1.00 \times 10^{-14} \text{ mol}^2 \text{ L}^{-2}$ at 298 K
(Self ionisation constant)

Molar volume (V_m) of an ideal gas at 273 K, 101.3 kPa (STP) = 22.4 L mol^{-1}

Molar volume (V_m) of an ideal gas at 298 K, 101.3 kPa (SLC) = 24.5 L mol^{-1}

Specific heat capacity (c) of water = $4.18 \text{ J g}^{-1} \text{ K}^{-1}$

Density (d) of water at 25°C = 1.00 g mL^{-1}

1 atm = 101.3 kPa = 760 mm Hg

0°C = 273 K

4. SI prefixes, their symbols and values

SI prefix	Symbol	Value
giga	G	10^9
mega	M	10^6
kilo	k	10^3
deci	d	10^{-1}
centi	c	10^{-2}
milli	m	10^{-3}
micro	μ	10^{-6}
nano	n	10^{-9}
pico	p	10^{-12}

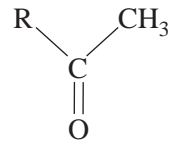
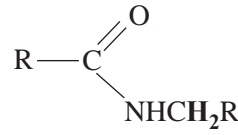
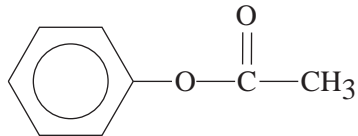
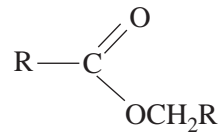
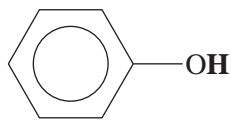
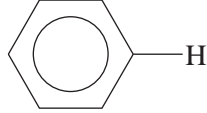
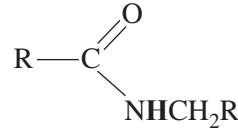
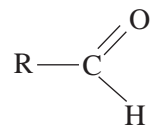
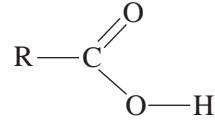
5. ^1H NMR data

Typical proton shift values relative to TMS = 0

These can differ slightly in different solvents. Where more than one proton environment is shown in the formula, the shift refers to the ones in bold letters.

Type of proton	Chemical shift (ppm)
R-CH ₃	0.9
R-CH ₂ -R	1.3
RCH = CH- CH₃	1.7
R ₃ -CH	2.0
$\text{CH}_3-\text{C} \begin{array}{l} \text{O} \\ \parallel \\ \text{OR} \end{array}$ or $\text{CH}_3-\text{C} \begin{array}{l} \text{O} \\ \parallel \\ \text{NHR} \end{array}$	2.0

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Type of proton	Chemical shift (ppm)
	2.1
R-CH ₂ -X (X = F, Cl, Br or I)	3-4
R-CH ₂ -OH	3.6
	3.2
R-O-CH ₃ or R-O-CH ₂ R	3.3
	2.3
	4.1
R-O-H	1-6 (varies considerably under different conditions)
R-NH ₂	1-5
RHC = CH ₂	4.6-6.0
	7.0
	7.3
	8.1
	9-10
	11.5

6. ¹³C NMR data

Type of carbon	Chemical shift (ppm)
R-CH ₃	8-25
R-CH ₂ -R	20-45
R ₃ -CH	40-60
R ₄ -C	36-45
R-CH ₂ -X	15-80
R ₃ C-NH ₂	35-70
R-CH ₂ -OH	50-90
RC≡CR	75-95
R ₂ C=CR ₂	110-150
RCOOH	160-185

7. Infrared absorption data

Characteristic range for infrared absorption

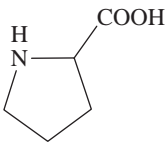
Bond	Wave number (cm ⁻¹)
C-Cl	700-800
C-C	750-1100
C-O	1000-1300
C=C	1610-1680
C=O	1670-1750
O-H (acids)	2500-3300
C-H	2850-3300
O-H (alcohols)	3200-3550
N-H (primary amines)	3350-3500

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8. 2-amino acids (α -amino acids)

Name	Symbol	Structure
alanine	Ala	$\begin{array}{c} \text{CH}_3 \\ \\ \text{H}_2\text{N}-\text{CH}-\text{COOH} \end{array}$
arginine	Arg	$\begin{array}{c} \text{NH} \\ \\ \text{CH}_2-\text{CH}_2-\text{CH}_2-\text{NH}-\text{C}-\text{NH}_2 \\ \\ \text{H}_2\text{N}-\text{CH}-\text{COOH} \end{array}$
asparagine	Asn	$\begin{array}{c} \text{O} \\ \\ \text{CH}_2-\text{C}-\text{NH}_2 \\ \\ \text{H}_2\text{N}-\text{CH}-\text{COOH} \end{array}$
aspartic acid	Asp	$\begin{array}{c} \text{CH}_2-\text{COOH} \\ \\ \text{H}_2\text{N}-\text{CH}-\text{COOH} \end{array}$
cysteine	Cys	$\begin{array}{c} \text{CH}_2-\text{SH} \\ \\ \text{H}_2\text{N}-\text{CH}-\text{COOH} \end{array}$
glutamine	Gln	$\begin{array}{c} \text{O} \\ \\ \text{CH}_2-\text{CH}_2-\text{C}-\text{NH}_2 \\ \\ \text{H}_2\text{N}-\text{CH}-\text{COOH} \end{array}$
glutamic acid	Glu	$\begin{array}{c} \text{CH}_2-\text{CH}_2-\text{COOH} \\ \\ \text{H}_2\text{N}-\text{CH}-\text{COOH} \end{array}$
glycine	Gly	$\text{H}_2\text{N}-\text{CH}_2-\text{COOH}$
histidine	His	$\begin{array}{c} \text{N} \\ // \quad \backslash \\ \text{CH}_2-\text{C} \quad \text{N}-\text{H} \\ \\ \text{H}_2\text{N}-\text{CH}-\text{COOH} \end{array}$
isoleucine	Ile	$\begin{array}{c} \text{CH}_3-\text{CH}-\text{CH}_2-\text{CH}_3 \\ \\ \text{H}_2\text{N}-\text{CH}-\text{COOH} \end{array}$

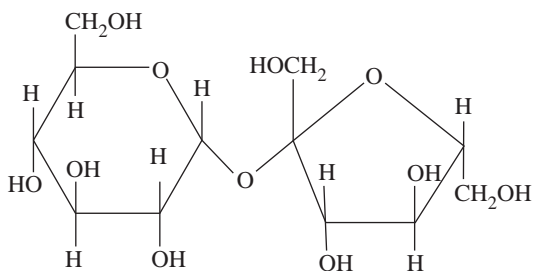
Name	Symbol	Structure
leucine	Leu	$\begin{array}{c} \text{CH}_3 - \text{CH} - \text{CH}_3 \\ \\ \text{CH}_2 \\ \\ \text{H}_2\text{N} - \text{CH} - \text{COOH} \end{array}$
lysine	Lys	$\begin{array}{c} \text{CH}_2 - \text{CH}_2 - \text{CH}_2 - \text{CH}_2 - \text{NH}_2 \\ \\ \text{H}_2\text{N} - \text{CH} - \text{COOH} \end{array}$
methionine	Met	$\begin{array}{c} \text{CH}_2 - \text{CH}_2 - \text{S} - \text{CH}_3 \\ \\ \text{H}_2\text{N} - \text{CH} - \text{COOH} \end{array}$
phenylalanine	Phe	$\begin{array}{c} \text{CH}_2 - \text{C}_6\text{H}_5 \\ \\ \text{H}_2\text{N} - \text{CH} - \text{COOH} \end{array}$
proline	Pro	
serine	Ser	$\begin{array}{c} \text{CH}_2 - \text{OH} \\ \\ \text{H}_2\text{N} - \text{CH} - \text{COOH} \end{array}$
threonine	Thr	$\begin{array}{c} \text{CH}_3 - \text{CH} - \text{OH} \\ \\ \text{H}_2\text{N} - \text{CH} - \text{COOH} \end{array}$
tryptophan	Trp	$\begin{array}{c} \text{H} \\ \\ \text{CH}_2 - \text{C}_8\text{H}_6\text{N}_2 \\ \\ \text{H}_2\text{N} - \text{CH} - \text{COOH} \end{array}$
tyrosine	Tyr	$\begin{array}{c} \text{CH}_2 - \text{C}_6\text{H}_4 - \text{OH} \\ \\ \text{H}_2\text{N} - \text{CH} - \text{COOH} \end{array}$
valine	Val	$\begin{array}{c} \text{CH}_3 - \text{CH} - \text{CH}_3 \\ \\ \text{H}_2\text{N} - \text{CH} - \text{COOH} \end{array}$

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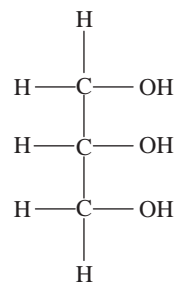
9. Formulas of some fatty acids

Name	Formula
Lauric	$C_{11}H_{23}COOH$
Myristic	$C_{13}H_{27}COOH$
Palmitic	$C_{15}H_{31}COOH$
Palmitoleic	$C_{15}H_{29}COOH$
Stearic	$C_{17}H_{35}COOH$
Oleic	$C_{17}H_{33}COOH$
Linoleic	$C_{17}H_{31}COOH$
Linolenic	$C_{17}H_{29}COOH$
Arachidic	$C_{19}H_{39}COOH$
Arachidonic	$C_{19}H_{31}COOH$

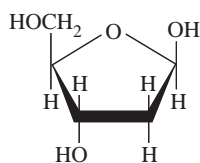
10. Structural formulas of some important biomolecules



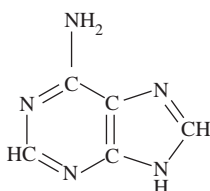
sucrose



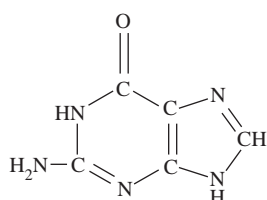
glycerol



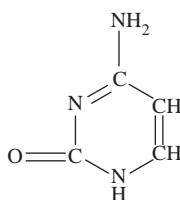
deoxyribose



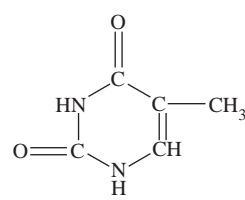
adenine



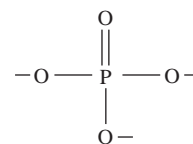
guanine



cytosine



thymine



phosphate

11. Acid-base indicators

Name	pH range	Colour change		K_a
		Acid	Base	
Thymol blue	1.2–2.8	red	yellow	2×10^{-2}
Methyl orange	3.1–4.4	red	yellow	2×10^{-4}
Bromophenol blue	3.0–4.6	yellow	blue	6×10^{-5}
Methyl red	4.2–6.3	red	yellow	8×10^{-6}
Bromothymol blue	6.0–7.6	yellow	blue	1×10^{-7}
Phenol red	6.8–8.4	yellow	red	1×10^{-8}
Phenolphthalein	8.3–10.0	colourless	red	5×10^{-10}

12. Acidity constants, K_a , of some weak acids at 25°C

Name	Formula	K_a
Ammonium ion	NH_4^+	5.6×10^{-10}
Benzoic	$\text{C}_6\text{H}_5\text{COOH}$	6.4×10^{-5}
Boric	H_3BO_3	5.8×10^{-10}
Ethanoic	CH_3COOH	1.7×10^{-5}
Hydrocyanic	HCN	6.3×10^{-10}
Hydrofluoric	HF	7.6×10^{-4}
Hypobromous	HOBr	2.4×10^{-9}
Hypochlorous	HOCl	2.9×10^{-8}
Lactic	$\text{HC}_3\text{H}_5\text{O}_3$	1.4×10^{-4}
Methanoic	HCOOH	1.8×10^{-4}
Nitrous	HNO_2	7.2×10^{-4}
Propanoic	$\text{C}_2\text{H}_5\text{COOH}$	1.3×10^{-5}

13. Values of molar enthalpy of combustion of some common fuels at 298 K and 101.3 kPa

Substance	Formula	State	ΔH_c (kJ mol ⁻¹)
hydrogen	H_2	g	-286
carbon (graphite)	C	s	-394
methane	CH_4	g	-889
ethane	C_2H_6	g	-1557
propane	C_3H_8	g	-2217
butane	C_4H_{10}	g	-2874
pentane	C_5H_{12}	l	-3509
hexane	C_6H_{14}	l	-4158
octane	C_8H_{18}	l	-5464
ethene	C_2H_4	g	-1409
methanol	CH_3OH	l	-725
ethanol	$\text{C}_2\text{H}_5\text{OH}$	l	-1364
1-propanol	$\text{CH}_3\text{CH}_2\text{CH}_2\text{OH}$	l	-2016
2-propanol	$\text{CH}_3\text{CHOHCH}_3$	l	-2003
glucose	$\text{C}_6\text{H}_{12}\text{O}_6$	s	-2816