VICTORIAN CURRICULUM AND ASSESSMENT AUTHORITY

Victorian Certificate of Education 2010

SUPERVISOR TO ATTACH PROCESSING LABEL HERE

STUDENT NUMBER

										Letter
Figures										
Words										

CHEMISTRY

Written examination 2

Thursday 11 November 2010

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	62
			Total 82

- 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 23 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

The factors which influence the rate of reaction between dilute hydrochloric acid and powdered calcium carbonate were investigated.

Which one of the following changes would **not** increase the rate of the reaction?

A. stirring the mixture

B. heating the reaction mixture

C. increasing the concentration of the acid

D. replacing the powder with a lump of calcium carbonate

Question 2

For an endothermic reaction

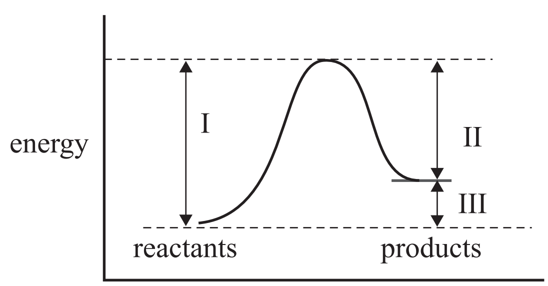
A. the enthalpy change is negative.

B. equilibrium can never be achieved.

C. the reaction absorbs energy from its surroundings.

D. the enthalpy of the reactants is higher than the enthalpy of the products.

Question 3



For a gas phase reaction, which of the quantities (I, II and III) in the energy profile diagram above are affected by decreasing the volume of the reaction vessel at constant temperature?

A. I and II only

B. I and III only

C. I, II and III

D. none of the quantities

SECTION A – continued

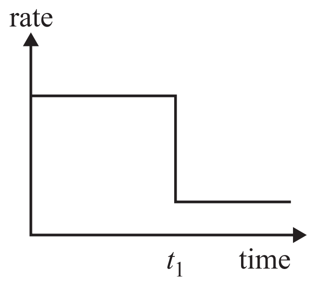
Questions 4 and 5 refer to the following information.

Reactants A and B are placed in a sealed container with a suitable catalyst where they react according to the equation

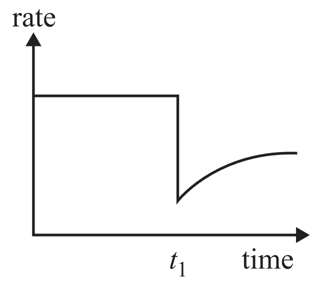
$$A(g) + B(g) \rightleftharpoons C(g)$$

After the reaction reaches equilibrium, a small amount of a compound is added to the container at time t_1.
The compound ‘poisons’ the catalyst and stops it working.

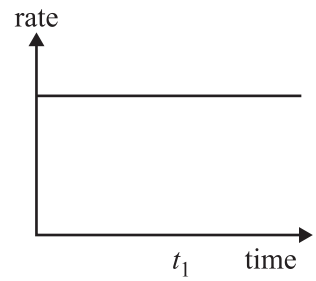
Question 4



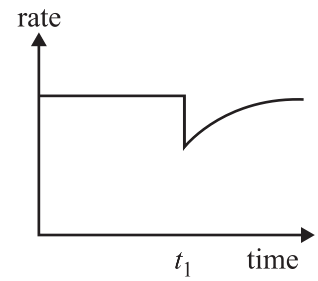
Graph I



Graph II



Graph III

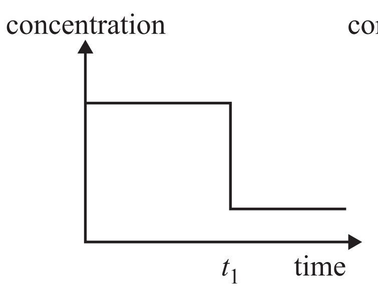


Graph IV

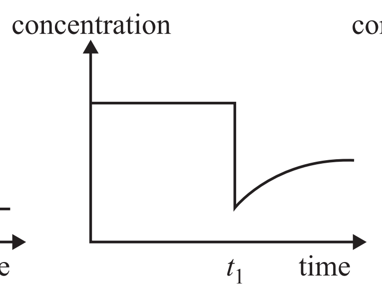
Which one of the graphs best represents the **rate** of the forward reaction versus time?

A. Graph I
B. Graph II
C. Graph III
D. Graph IV

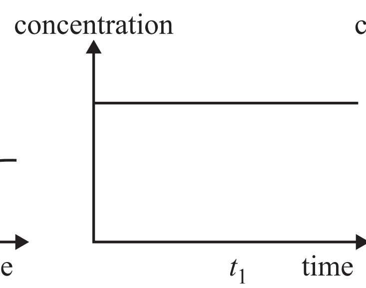
Question 5



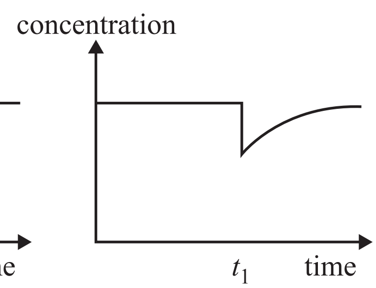
Graph I



Graph II



Graph III



Graph IV

Which one of the graphs best represents the **concentration** of product C versus time?

A. Graph I
B. Graph II
C. Graph III
D. Graph IV

Question 6

Nitrosyl chloride (NOCl) is a highly toxic gas that decomposes according to the equation

$$2NOCl(g) \rightleftharpoons 2NO(g) + Cl_2(g)$$

To investigate the reaction, 1.2 mol of NOCl(g) is placed in an empty 1.0 L flask and allowed to reach equilibrium. The flask and its contents are kept at a constant temperature.

If $[Cl_2]$ = 0.20 M at equilibrium, what is the equilibrium concentration of NOCl(g)?

A. 0.80 M
B. 1.00 M
C. 1.10 M
D. 1.40 M

Question 7

The following reaction systems are at equilibrium in separate sealed containers. The volumes of the containers are halved at constant temperature.

Which reaction has the largest percentage change in the concentration fraction (reaction quotient) immediately after the volume change?

A. $N_2O_4(g) \rightleftharpoons 2NO_2(g)$
B. $H_2(g) + I_2(g) \rightleftharpoons 2HI(g)$
C. $2CO_2(g) \rightleftharpoons 2CO(g) + O_2(g)$
D. $CO(g) + 2H_2(g) \rightleftharpoons CH_3OH(g)$

Question 8

A 10 mL sample of 0.010 M HCl is diluted by adding distilled water at constant temperature.

Which one of the following items correctly shows the effect of the dilution on the concentrations of H^+ and OH^- ions in the solution?

	$[H^+]$	$[OH^-]$
A.	decrease	decrease
B.	decrease	increase
C.	increase	decrease
D.	increase	increase

Question 9

A chemist prepares 0.10 M aqueous solutions of each of the following acids.

Which solution has the lowest pH?

A. CH_3COOH
B. HNO_2
C. HCN
D. HOCl

NO WRITING ALLOWED IN THIS AREA

Question 10

Barium hydroxide is soluble in water.

The pH at 25 °C of a 0.0050 M solution of $Ba(OH)_2$ is

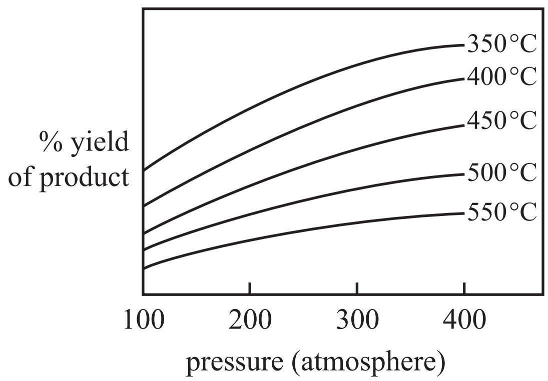
A. 2.0
B. 2.3
C. 11.7
D. 12.0

Questions 11 and 12 refer to the following information.

The graph below refers to the following gaseous reaction.

$$aA(g) + bB(g) \rightleftharpoons cC(g) + dD(g)$$

The effect of increasing pressure and temperature on the equilibrium yield of the products is shown in the graph below.



Question 11

Which one of the following statements about the relative number of reactant and product molecules in the balanced equation is true?

A. The number of reactant molecules is equal to the number of product molecules.
B. The number of reactant molecules is greater than the number of product molecules.
C. The number of reactant molecules is less than the number of product molecules.
D. The relative number of reactant and product molecules cannot be determined from the data provided.

Question 12

Which one of the following statements about this gaseous reaction is true?

A. The reaction is exothermic because the yield increases as the temperature increases.
B. The reaction is endothermic because the yield increases as the temperature increases.
C. The reaction is exothermic because the yield decreases as the temperature increases.
D. The reaction is endothermic because the yield decreases as the temperature increases.

Question 13

Magnesium metal burns in air with an intense bright light according to the equation

$$2\,Mg(s) + O_2(g) \rightarrow 2\,MgO(s) \qquad \Delta H = -1200 \text{ kJ mol}^{-1}$$

How much energy is released when 7.29 g of magnesium is burned?

A. 8 kJ
B. 16 kJ
C. 180 kJ
D. 360 kJ

Question 14

The combustion of ethanol occurs according to the equation

$$C_2H_5OH(l) + 3O_2(g) \rightarrow 2CO_2(g) + 3H_2O(g) \qquad \Delta H = -1364 \text{ kJ mol}^{-1}$$

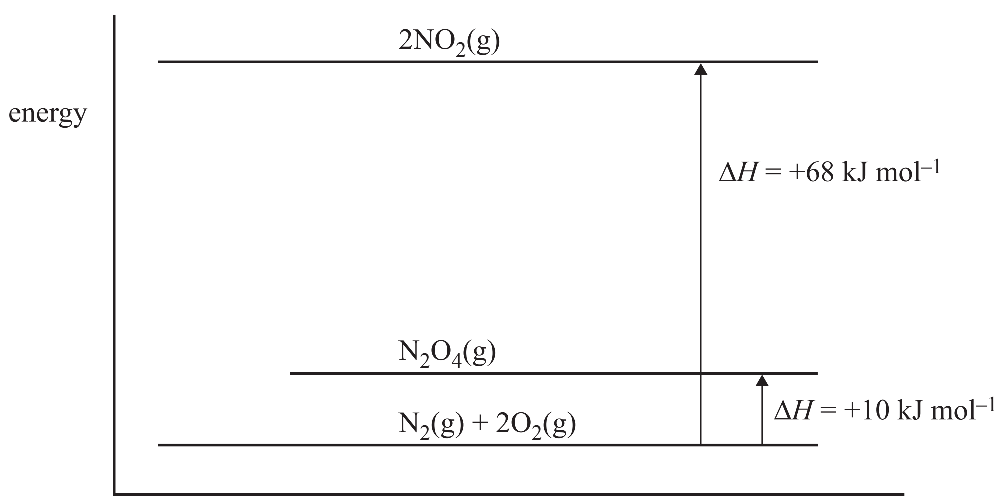
This means that

A. burning 1.0 g of liquid ethanol produces 1364 kJ of energy.
B. two moles of liquid ethanol burns to produce 2728 kJ of energy.
C. 1364 kJ of energy is produced when one mole of gaseous ethanol is burned.
D. the activation energy for the combustion of one mole of liquid ethanol is 1364 kJ.

Question 15

The energy diagram below relates to the following two reactions.

$$N_2(g) + 2O_2(g) \rightarrow 2NO_2(g) \qquad \Delta H = +68 \text{ kJ mol}^{-1}$$
$$N_2(g) + 2O_2(g) \rightarrow N_2O_4(g) \qquad \Delta H = +10 \text{ kJ mol}^{-1}$$



The enthalpy change for the reaction $NO_2(g) \rightarrow \frac{1}{2} N_2O_4(g)$ will be

A. $+58 \text{ kJ mol}^{-1}$
B. $+29 \text{ kJ mol}^{-1}$
C. -58 kJ mol^{-1}
D. -29 kJ mol^{-1}

Question 16

Which of the following represents a balanced reduction half-reaction?

A. $VO_2^+ + H^+ + 2e^- \rightarrow VO^{2+} + H_2O$

B. $VO_2^+ + H_2 \rightarrow VO^{2+} + H_2O + e^-$

C. $VO_2^+ + 2H^+ + e^- \rightarrow VO^{2+} + H_2O$

D. $VO_2^+ + 4H^+ + 3e^- \rightarrow VO^{2+} + 2H_2O$

Question 17

Identify the strongest oxidant and the strongest reductant in the following half-equations.

$$Ca^{2+}(aq) + 2e^- \rightleftharpoons Ca(s)$$

$$I_2(s) + 2e^- \rightleftharpoons 2I^-(aq)$$

	Strongest oxidant	Strongest reductant
A.	Ca^{2+}	I^-
B.	I_2	Ca
C.	Ca	I_2
D.	I^-	Ca^{2+}

Question 18

A direct electric current is passed through 1.0 M K_2SO_4 solution using inert electrodes. The following standard reduction potential is provided in addition to those in the Data Book.

$$S_2O_8^{2-}(aq) + 2e^- \rightleftharpoons 2SO_4^{2-}(aq) \qquad E^0 = 2.01 \text{ V}$$

Which one of the following equations represents the reaction that occurs at the anode?

A. $2SO_4^{2-}(aq) \rightleftharpoons S_2O_8^{2-}(aq) + 2e^-$

B. $2H_2O(l) \rightleftharpoons O_2(g) + 4H^+ + 4e^-$

C. $2H_2O(l) + 2e^- \rightleftharpoons H_2(g) + 2OH^-(aq)$

D. $K^+(aq) + e^- \rightleftharpoons K(s)$

Question 19

Which one of the following statements is **true** for both fuel cells and rechargeable cells?

A. All reactants are stored within the cell.

B. Reaction products are continuously removed from the cell.

C. Electrons pass from the reductant to the anode as electricity is produced.

D. Electrical energy is converted to chemical energy as the cell is recharged.

Question 20

Why is it not possible to plate an object with magnesium metal using an aqueous 1.0 M MgI_2 solution as the electrolyte?

A. Water is a stronger reductant than I^-

B. Water is a stronger oxidant than I^-

C. Water is a stronger reductant than Mg^{2+}

D. Water is a stronger oxidant than Mg^{2+}

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, $H_2(g)$; $NaCl(s)$

Question 1

a. The most common method for the industrial production of hydrogen is the **steam reforming process**, which requires high temperature, high pressure and a Ni catalyst.

The equation for this reaction is

$$CH_4(g) + H_2O(g) \rightleftharpoons CO(g) + 3H_2(g) \qquad \Delta H = +207 \text{ kJ mol}^{-1}$$

i. Write an equilibrium expression for the **steam reforming** reaction.

ii. Le Chatelier's principle indicates that equilibrium yield for the reaction above is favoured by low pressure. Suggest one reason why high pressure is used in the industrial process described above.

At 1500 °C the concentrations of the gases in a particular equilibrium mixture were found to be

$$[CH_4] = 0.400 \text{ M}, \quad [CO] = 0.300 \text{ M}, \quad [H_2O] = 0.068 \text{ M}$$

K = 5.67 M^2 at 1500 °C for the reaction.

iii. Calculate the molar concentration of H_2 in the equilibrium mixture.

1 + 1 + 2 = 4 marks

SECTION B – Question 1 – continued

b. Methane can be obtained from natural gas deposits **or** as a biochemical fuel from biomass.

i. Which of these sources of methane would be considered more sustainable? Explain your answer.

ii. Energy density may be defined as the amount of energy released per gram of fuel. Use molar enthalpy of combustion data to calculate the energy density of hydrogen gas in kJ g^{-1}.

Both hydrogen and methane can be burned to produce heat energy.

iii. Calculate the volume of hydrogen gas in L, at SLC, that produces the same amount of energy as 2.0 L of methane gas at SLC.

2 + 1 + 4 = 7 marks

Total 11 marks

Question 2

a. Lactic acid, $CH_3CH(OH)COOH$, is a weak acid found in milk. The molar mass of lactic acid is 90.0 g mol^{-1}. In an experiment a student dissolved 4.50 g of lactic acid in 500.0 mL of water.

$$CH_3CH(OH)COOH(l) + H_2O(l) \rightleftharpoons CH_3CH(OH)COO^-(aq) + H_3O^+(aq)$$

i. Calculate the equilibrium molar concentration of H_3O^+ ions in the lactic acid solution.

ii. Calculate the pH for the lactic acid solution.

iii. Calculate the percentage ionisation of lactic acid in this experiment.

iv. State one assumption that you made when calculating your answer to **part i.**

4 + 1 + 1 + 1 = 7 marks

b. A 1.0 M solution of lactic acid is prepared at 25 °C.
When distilled water is added to this solution

i. the pH will **decrease** **increase** **not change**

(circle the correct answer)

ii. the percentage ionisation of the acid will **decrease** **increase** **not change**

(circle the correct answer)

iii. Provide an explanation for your answer to **part ii.**

___

___

___

1 + 1 + 1 = 3 marks

Total 10 marks

Question 3

Many industrial processes create waste products such as chimney gases. These gases may contain serious atmospheric pollutants, such as oxides of nitrogen (for example, NO and NO_2).

One way to remove these nitrogen oxides is to treat the chimney gases with ammonia. This treatment converts the oxides of nitrogen in the chimney gases to nitrogen and water. These are then released into the atmosphere.

a. **i.** Determine the coefficients that correctly balance the equation for this reaction. Write your answers in the spaces provided.

$$\_\_\_\_\ NO(g) + \_\_\_\_\ NH_3(g) \rightarrow \_\_\_\_\ N_2(g) + \_\_\_\_\ H_2O(g)$$

It is important to adjust the amount of ammonia mixing with the chimney gases to give the correct mole ratio of ammonia to nitrogen(II) oxide, NO.

ii. Explain the effect on the composition of the gases released into the atmosphere if the amount of ammonia was

too low

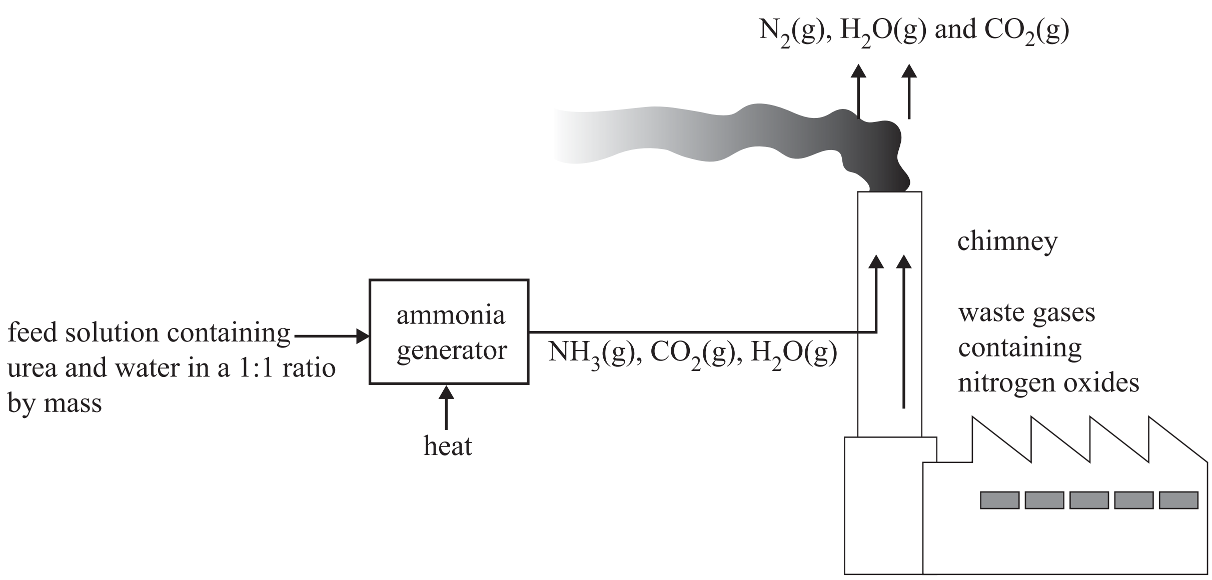
____

too high

____

1 + 2 = 3 marks

b. The ammonia can be produced on-site in industrial plants using small-scale ammonia generators. The ammonia is produced by reacting urea with water. A simplified diagram of such a plant is provided below.



The chemical reaction occurring in the ammonia generator is

$$(NH_2)_2CO(aq) + H_2O(l) \rightleftharpoons 2NH_3(aq) + CO_2(aq) \qquad \Delta H + \text{ve}$$

In a particular generator a 1:1 **mass** ratio of urea and water is used.

i. Which reactant is in excess?

____

ii. Give one reason why an excess of one reactant is used in this chemical reaction.

Changing the temperature of the reaction mixture in the ammonia generator can control the amount of ammonia gas produced.

iii. Explain the effect of increasing the temperature on the amount of ammonia formed in the generator.

1 + 1 + 2 = 4 marks

The table gives some of the properties of ammonia and urea.

	ammonia	**urea**
Physical state at room temperature	gas	solid
Chemical reactivity	high	low
Toxicity	high	low
Flammability	low	low

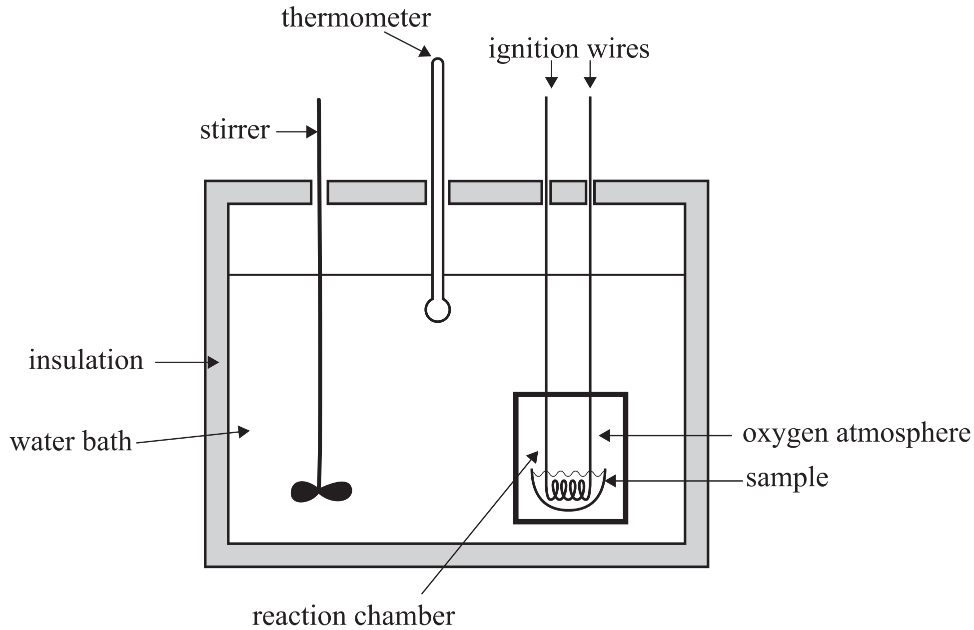
c. Give one advantage, other than cost, of producing ammonia on-site by this method rather than having large quantities of ammonia delivered from a plant at another location.

1 mark

Total 8 marks

Question 4

Below is a diagram of a bomb calorimeter which can be used to determine the enthalpy changes in combustion reactions. The sample is placed in the reaction chamber or 'bomb' which has a volume of 50.0 cm^3. The chamber is then sealed and pure oxygen is pumped into the bomb to a pressure of 25 atm. The reaction chamber is then placed into the water bath.



Solid benzoic acid, C_6H_5COOH, is commonly used to calibrate bomb calorimeters. 1 mol of benzoic acid releases 3227 kJ of heat energy when completely combusted.

a. Write a thermochemical equation for the complete combustion of benzoic acid, including a ΔH value.

3 marks

b. A 1.025 g sample of benzoic acid was placed into the bomb. Pure oxygen was also pumped into the bomb to a pressure of 25 atm. The complete combustion of the benzoic acid created a 2.17 °C temperature rise in the surrounding water bath. The molar mass of benzoic acid is 122.0 g mol^{-1}.

i. Why must the oxygen be pumped into the bomb at high pressure?

ii. Calculate the calibration factor for the bomb calorimeter. Express your answer to the correct number of significant figures and include appropriate units.

iii. Would the value of the calibration factor be higher, lower or the same if the calibration was conducted on this calorimeter without its insulation? Explain.

1 + 4 + 2 = 7 marks

Total 10 marks

Question 5

During this semester you have studied the production of one of the following chemicals.

Circle the chemical you have studied this semester.

ammonia ethene sulfuric acid nitric acid

a. A catalyst plays an important part in the production of your selected chemical.

i. Write a balanced equation for a chemical reaction where a catalyst is used. (If you have studied the production of ammonia do not include the steam reforming reaction in your answer.)

ii. Name the catalyst.

iii. Explain how a catalyst increases the rate of a chemical reaction at a given temperature.

1 + 1 + 1 = 3 marks

b. Chemical laboratories and production plants carry out risk assessments on the procedures involving chemicals they use or produce.

i. Identify one specific chemical hazard associated with the handling of your selected chemical.

ii. Identify one risk to humans of exposure to the chemical hazard you identified.

iii. Give one action that can be taken to reduce the risk of human exposure to the chemical hazard you identified.

1 + 1 + 1 = 3 marks

Total 6 marks

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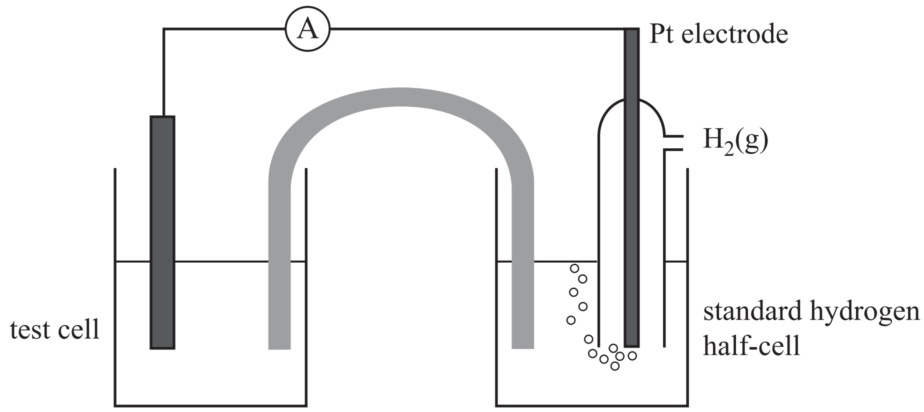
Question 6

In a problem-solving activity a student is given the following information regarding three half-equations. However, although the three numerical values of E^0 are correct, they have been incorrectly assigned to the three half-equations.

Half-equation	$\mathbf{E^0}$
$AgCl(s) + e \rightleftharpoons Ag(s) + Cl^-(aq)$	–0.40 V
$Cd^{2+}(aq) + 2e \rightleftharpoons Cd(s)$	–0.36 V
$PbSO_4(s) + 2e \rightleftharpoons Pb(s) + SO_4^{2-}(aq)$	+0.22 V

The objective of this task is to correctly assign the E^0 values to the corresponding half-equation.

To do this, the student constructs standard half-cells for each of the above half-reactions. These half-cells are connected, one at a time, to a standard hydrogen half-cell as indicated in the diagram below.



The following observations were made either during or after the electrochemical cell discharged electricity for several minutes.

Experiment	**Half-cell reaction being investigated**	**Experimental notes**
1	$AgCl(s) + e \rightleftharpoons Ag(s) + Cl^-(aq)$	Electron flow was detected passing from the standard hydrogen half-cell to the half-cell containing the silver electrode.
2	$Cd^{2+}(aq) + 2e \rightleftharpoons Cd(s)$	The mass of the cadmium electrode decreased.
3	$PbSO_4(s) + 2e \rightleftharpoons Pb(s) + SO_4^{2-}(aq)$	The pH of the solution in the standard hydrogen half-cell increased.

a. The above information can only be used to assign **one** of the E^0 values to its corresponding half-equation. Identify this half-equation by placing the correct E^0 value next to its corresponding half-equation in the table below.

Half-equation	$\mathbf{E^0}$
$AgCl(s) + e \rightleftharpoons Ag(s) + Cl^-(aq)$	
$Cd^{2+}(aq) + 2e \rightleftharpoons Cd(s)$	
$PbSO_4(s) + 2e \rightleftharpoons Pb(s) + SO_4^{2-}(aq)$	

2 marks

b. Explain why the other two E^0 values cannot be correctly assigned to their half-equations.

1 mark

c. Explain why the pH of the solution in the standard hydrogen half-cell increased in experiment 3.

1 mark

Total 4 marks

Question 7

The **lithium button cell**, used to power watches and calculators, is a primary cell containing lithium metal. The **lithium ion cell** is a secondary cell that is used to power laptop computers.

a. What is the difference between a primary and secondary cell?

1 mark

b. By referring to information provided in the Data Book, give one reason why lithium is used as a reactant in these galvanic cells.

1 mark

Some early lithium metal batteries exploded when exposed to water.

c. Write a balanced equation, including states, for the reaction between lithium metal and water to explain why an explosion might occur.

3 marks

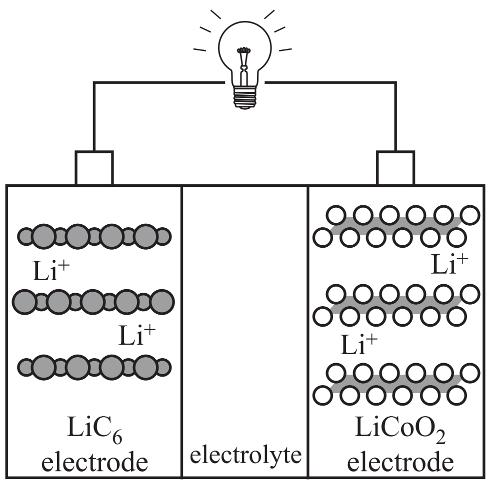
In lithium ion cells, lithium ions move between the electrodes as the cell is discharged and recharged. The negative electrode consists of lithiated graphite, LiC_6, and the positive electrode consists of lithium cobalt oxide, $LiCoO_2$.

The chemical reactions that take place in the lithium ion cell are complex. The following equations present a simplified description of the reactions that occur at the electrodes as the cell is **recharged**.

positive electrode $LiCoO_2 \rightarrow CoO_2 + Li^+ + e^-$

negative electrode $6C + Li^+ + e^- \rightarrow LiC_6$

d. On the diagram below, use arrows to indicate the directions of movement of electrons, e^-, and Li^+ ions as the lithium ion cell is **discharged**.



2 marks

Lithium metal is produced by the electrolysis of molten lithium chloride, LiCl.

e. Calculate the mass of lithium metal produced in 48.0 hours using a current of 6.50 amps.

3 marks

Total 10 marks

Question 8

A student made the following notes about the phosphoric acid fuel cell using information obtained from various texts and websites.

Electrolyte: *Liquid phosphoric acid.* H_3PO_4

Equations

Anode reaction: $H_2(g) \rightarrow 2H^+(\text{in phosphoric acid}) + 2e^-$

Cathode reaction: $O_2(g) + 4H^+(\text{in phosphoric acid}) + 4e^- \rightarrow 2H_2O(g)$

Operating temperature 190 °C

The student also made the following notes regarding the electrochemical series.

It is possible to predict the voltage output of a standard cell by using E^0 *values and the formula*

Cell voltage = E^0*(cathode reaction)* – E^0*(anode reaction)*

Using the following equations and E^0 *values from the electrochemical series*

$O_2(g) + 4H^+(aq) + 4e^- \rightarrow 2H_2O(l)$ $E^0 = 1.23\ V$

$2H^+(aq) + 2e^- \rightarrow H_2(g)$ $E^0 = 0.00\ V$

Phosphoric acid fuel cell voltage = E^0*(cathode reaction)* – E^0*(anode reaction)*

= 1.23 V – 0.00 V

= 1.23 V

Hence the predicted voltage according to the electrochemical series is 1.23 V.

However, the actual voltage produced by this fuel cell is 0.7 V.

a. Give **two** specific reasons why the phosphoric acid fuel cell does not produce the 1.23 volts predicted by the student.

2 marks

b. Write a balanced equation for the overall reaction that occurs in the phosphoric acid fuel cell.

1 mark

Total 3 marks

END OF QUESTION AND ANSWER BOOK

VICTORIAN CURRICULUM AND ASSESSMENT AUTHORITY

Victorian Certificate of Education
2010

CHEMISTRY

Written examination

Thursday 11 November 2010

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.

Table of contents

1. Periodic table of the elements

Key:

- atomic number: **79**
- symbol of element: **Au**
- relative atomic mass: 197.0
- name of element: Gold

1 **H** 1.0 Hydrogen																	**2** **He** 4.0 Helium
3 **Li** 6.9 Lithium	**4** **Be** 9.0 Beryllium											**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	**10** **Ne** 20.1 Neon
11 **Na** 23.0 Sodium	**12** **Mg** 24.3 Magnesium											**13** **Al** 27.0 Aluminium	**14** **Si** 28.1 Silicon	**15** **P** 31.0 Phosphorus	**16** **S** 32.1 Sulfur	**17** **Cl** 35.5 Chlorine	**18** **Ar** 39.9 Argon
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	**72** **Hf** 178.5 Hafnium	**73** **Ta** 180.9 Tantalum	**74** **W** 183.8 Tungsten	**75** **Re** 186.2 Rhenium	**76** **Os** 190.2 Osmium	**77** **Ir** 192.2 Iridium	**78** **Pt** 195.1 Platinum	**79** **Au** 197.0 Gold	**80** **Hg** 200.6 Mercury	**81** **Tl** 204.4 Thallium	**82** **Pb** 207.2 Lead	**83** **Bi** 209.0 Bismuth	**84** **Po** (209) Polonium	**85** **At** (210) Astatine	**86** **Rn** (222) Radon
87 **Fr** (223) Francium	**88** **Ra** (226) Radium	**89** **Ac** (227) Actinium	**104** **Rf** (261) Rutherfordium	**105** **Db** (262) Dubnium	**106** **Sg** (266) Seaborgium	**107** **Bh** (264) Bohrium	**108** **Hs** (277) Hassium	**109** **Mt** (268) Meitnerium	**110** **Ds** (271) Darmstadtium	**111** **Rg** (272) Roentgenium	**112** **Uub**		**114** **Uuq**		**116** **Uuh**		**118** **Uuo**

58 **Ce** 140.1 Cerium	**59** **Pr** 140.9 Praseodymium	**60** **Nd** 144.2 Neodymium	**61** **Pm** (145) Promethium	**62** **Sm** 150.3 Samarium	**63** **Eu** 152.0 Europium	**64** **Gd** 157.2 Gadolinium	**65** **Tb** 158.9 Terbium	**66** **Dy** 162.5 Dysprosium	**67** **Ho** 164.9 Holmium	**68** **Er** 167.3 Erbium	**69** **Tm** 168.9 Thulium	**70** **Yb** 173.0 Ytterbium	**71** **Lu** 175.0 Lutetium

90 **Th** 232.0 Thorium	**91** **Pa** 231.0 Protactinium	**92** **U** 238.0 Uranium	**93** **Np** (237.1) 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

2. The electrochemical series

	$E°$ in volt
$F_2(g) + 2e^- \rightleftharpoons 2F^-(aq)$	+2.87
$H_2O_2(aq) + 2H^+(aq) + 2e^- \rightleftharpoons 2H_2O(l)$	+1.77
$Au^+(aq) + e^- \rightleftharpoons Au(s)$	+1.68
$Cl_2(g) + 2e^- \rightleftharpoons 2Cl^-(aq)$	+1.36
$O_2(g) + 4H^+(aq) + 4e^- \rightleftharpoons 2H_2O(1)$	+1.23
$Br_2(l) + 2e^- \rightleftharpoons 2Br^-(aq)$	+1.09
$Ag^+(aq) + e^- \rightleftharpoons Ag(s)$	+0.80
$Fe^{3+}(aq) + e^- \rightleftharpoons Fe^{2+}(aq)$	+0.77
$O_2(g) + 2H^+(aq) + 2e^- \rightleftharpoons H_2O_2(aq)$	+0.68
$I_2(s) + 2e^- \rightleftharpoons 2I^-(aq)$	+0.54
$O_2(g) + 2H_2O(l) + 4e^- \rightleftharpoons 4OH^-(aq)$	+0.40
$Cu^{2+}(aq) + 2e^- \rightleftharpoons Cu(s)$	+0.34
$Sn^{4+}(aq) + 2e^- \rightleftharpoons Sn^{2+}(aq)$	+0.15
$S(s) + 2H^+(aq) + 2e^- \rightleftharpoons H_2S(g)$	+0.14
$2H^+(aq) + 2e^- \rightleftharpoons H_2(g)$	0.00
$Pb^{2+}(aq) + 2e^- \rightleftharpoons Pb(s)$	–0.13
$Sn^{2+}(aq) + 2e^- \rightleftharpoons Sn(s)$	–0.14
$Ni^{2+}(aq) + 2e^- \rightleftharpoons Ni(s)$	–0.23
$Co^{2+}(aq) + 2e^- \rightleftharpoons Co(s)$	–0.28
$Fe^{2+}(aq) + 2e^- \rightleftharpoons Fe(s)$	–0.44
$Zn^{2+}(aq) + 2e^- \rightleftharpoons Zn(s)$	–0.76
$2H_2O(l) + 2e^- \rightleftharpoons H_2(g) + 2OH^-(aq)$	–0.83
$Mn^{2+}(aq) + 2e^- \rightleftharpoons Mn(s)$	–1.03
$Al^{3+}(aq) + 3e^- \rightleftharpoons Al(s)$	–1.67
$Mg^{2+}(aq) + 2e^- \rightleftharpoons Mg(s)$	–2.34
$Na^+(aq) + e^- \rightleftharpoons Na(s)$	–2.71
$Ca^{2+}(aq) + 2e^- \rightleftharpoons Ca(s)$	–2.87
$K^+(aq) + e^- \rightleftharpoons K(s)$	–2.93
$Li^+(aq) + e^- \rightleftharpoons Li(s)$	–3.02

3. Physical constants

Avogadro's constant (N_A) = 6.02×10^{23} mol^{-1}

Charge on one electron = -1.60×10^{-19} C

Faraday constant (F) = 96 500 C mol^{-1}

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

Ionic product for water (K_w) = 1.00×10^{-14} mol^2 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 J g^{-1} 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

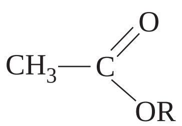
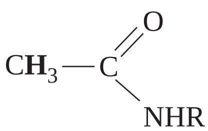
4. SI prefixes, their symbols and values

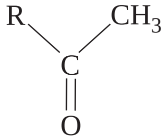
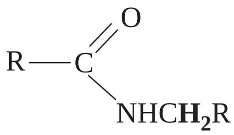
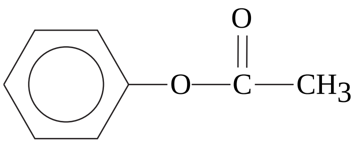
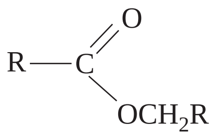
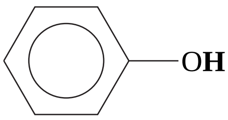
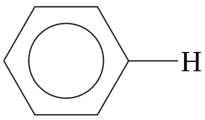
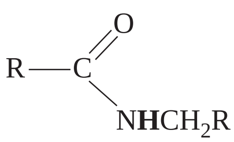
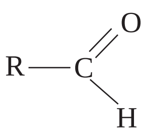
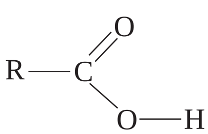
SI prefix	Symbol	Value
giga	G	10^9
mega	M	10^6
kilo	k	10^3
deci	d	10^{-1}
centi	c	10^{-2}
milli	m	10^{-3}
micro	μ	10^{-6}
nano	n	10^{-9}
pico	p	10^{-12}

5. ^{1}H 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
$RCH = CH–C\mathbf{H_3}$	1.7
$R_3–CH$	2.0
 or 	2.0

Type of proton	Chemical shift (ppm)
	2.1
$R{-}CH_2{-}X$ (X = F, Cl, Br or I)	3–4
R–C**H₂**–OH	3.6
	3.2
$R{-}O{-}CH_3$ or $R{-}O{-}CH_2R$	3.3
	2.3
	4.1
R–O–H	1–6 (varies considerably under different conditions)
$R{-}NH_2$	1–5
RHC=C**H**₂	4.6–6.0
	7.0
	7.3
	8.1
	9–10
	11.5

6. ^{13}C NMR data

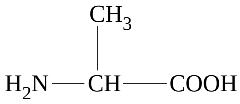
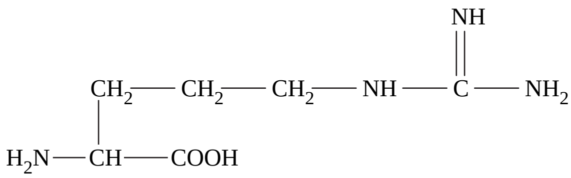
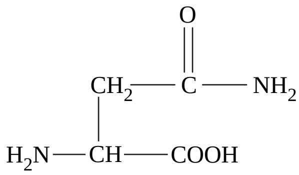
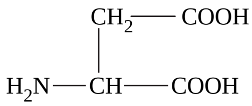
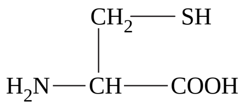
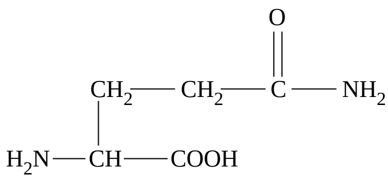
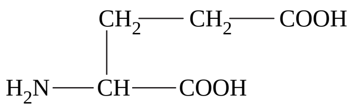
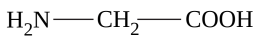
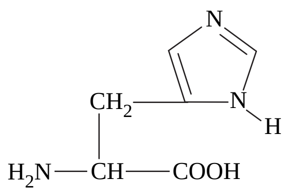
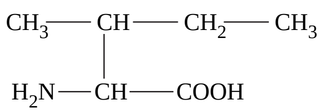
Type of carbon	**Chemical shift (ppm)**
R–CH_3	8–25
R–CH_2–R	20–45
R_3–CH	40–60
R_4–C	36–45
R–CH_2–X	15–80
R_3C–NH_2	35–70
R–CH_2–OH	50–90
RC≡CR	75–95
R_2C=CR_2	110–150
RCOOH	160–185

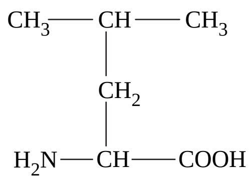
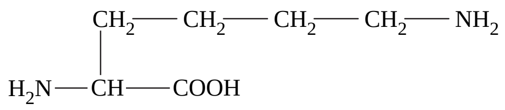
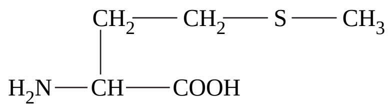
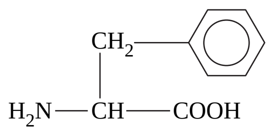
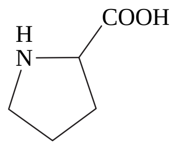
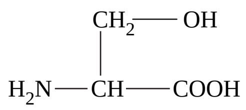
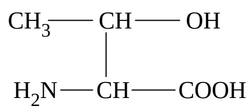
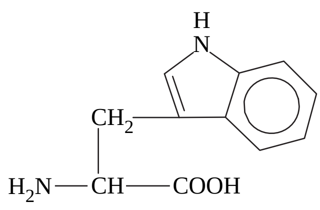
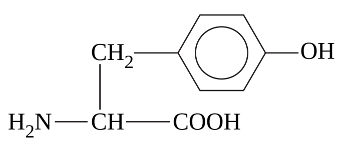
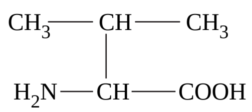
7. Infrared absorption data

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

8. 2-amino acids (*α*-amino acids)

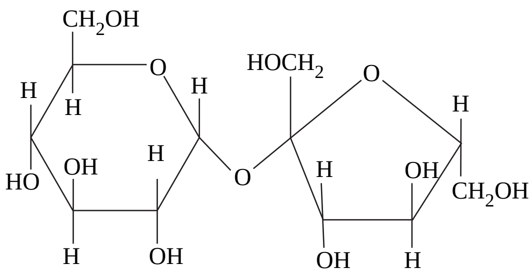
Name	Symbol	Structure
alanine	Ala	
arginine	Arg	
asparagine	Asn	
aspartic acid	Asp	
cysteine	Cys	
glutamine	Gln	
glutamic acid	Glu	
glycine	Gly	
histidine	His	
isoleucine	Ile	

Name	**Symbol**	**Structure**
leucine	Leu	
lysine	Lys	
methionine	Met	
phenylalanine	Phe	
proline	Pro	
serine	Ser	
threonine	Thr	
tryptophan	Trp	
tyrosine	Tyr	
valine	Val	

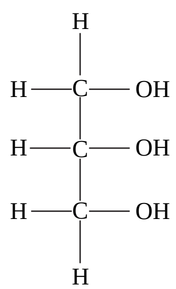
9. Formulas of some fatty acids

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	$C_{19}H_{31}COOH$

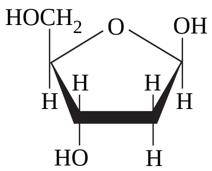
10. Structural formulas of some important biomolecules



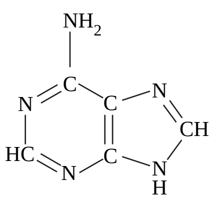
sucrose



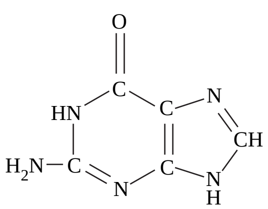
glycerol



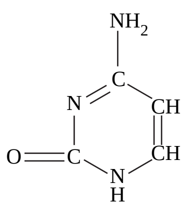
deoxyribose



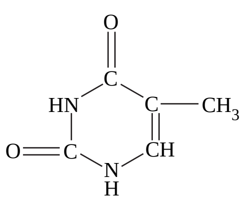
adenine



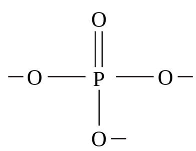
guanine



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

Name	Formula	K_a
Ammonium ion	NH_4^+	5.6×10^{-10}
Benzoic	C_6H_5COOH	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	$HC_3H_5O_3$	1.4×10^{-4}
Methanoic	HCOOH	1.8×10^{-4}
Nitrous	HNO_2	7.2×10^{-4}
Propanoic	C_2H_5COOH	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	C_2H_5OH	l	–1364
1-propanol	$CH_3CH_2CH_2OH$	l	–2016
2-propanol	$CH_3CHOHCH_3$	l	–2003
glucose	$C_6H_{12}O_6$	s	–2816

END OF DATA BOOK