VICTORIAN CURRICULUM AND ASSESSMENT AUTHORITY

Victorian Certificate of Education
2008

SUPERVISOR TO ATTACH PROCESSING LABEL HERE

STUDENT NUMBER

Figures									Letter:
Words									

CHEMISTRY

Written examination 2

Thursday 13 November 2008

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	9	9	59
			Total 79

- 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 24 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.

Questions 1, 2 and 3 refer to the following information.

The following gaseous equilibrium is established at high temperatures in the presence of a finely divided nickel (Ni) catalyst.

$$CH_4(g) + H_2O(g) \rightleftharpoons CO(g) + 3H_2(g); \; \Delta H = +206 \text{ kJ mol}^{-1}$$

Question 1

A particular reaction is carried out using equal amounts of $CH_4(g)$ and $H_2O(g)$.

Which one of the following sets of changes in conditions would lead to the greatest increase in the proportion of the reactants converted to products?

	Volume of reaction vessel	**Temperature**
A.	increased	increased
B.	increased	decreased
C.	decreased	increased
D.	decreased	decreased

Question 2

This reaction occurs at a measurable rate only when the finely divided catalyst is present.

This catalyst increases the reaction rate because

A. it strongly attracts the reaction products, driving the reaction to the right.

B. the reactants can become attached to its surface where they can meet and undergo reaction.

C. it provides energy to the reactants when their molecules bounce off it, increasing the proportion of molecules in the gas state with the required activation energy.

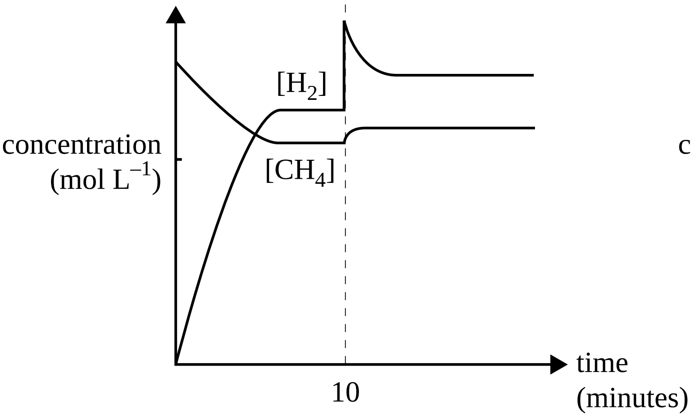
D. it increases the equilibrium constant of the reaction, causing an increase in the proportion of products at equilibrium.

Question 3

Equal amounts of CH_4(g) and H_2O(g) are added to a reaction vessel and allowed to react. After 10 minutes, equilibrium has been reached. At that time, some H_2 is added to the mixture and equilibrium is re-established.

Which one of the following graphs best represents the changes in the amounts of CH_4 and H_2 in the reaction mixture?

A.



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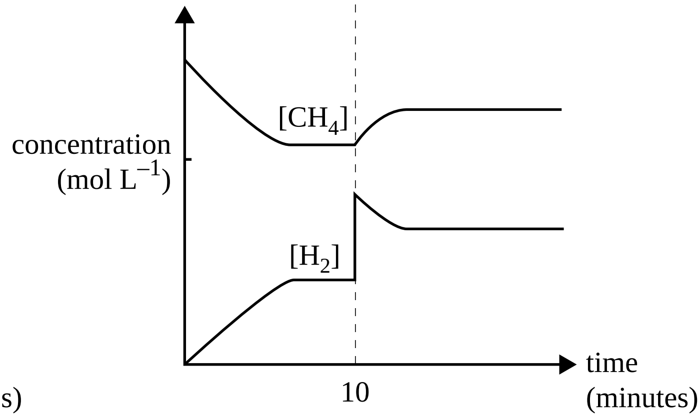

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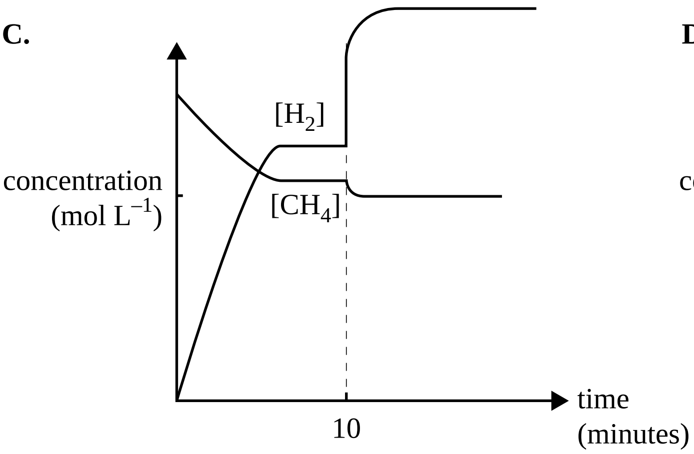

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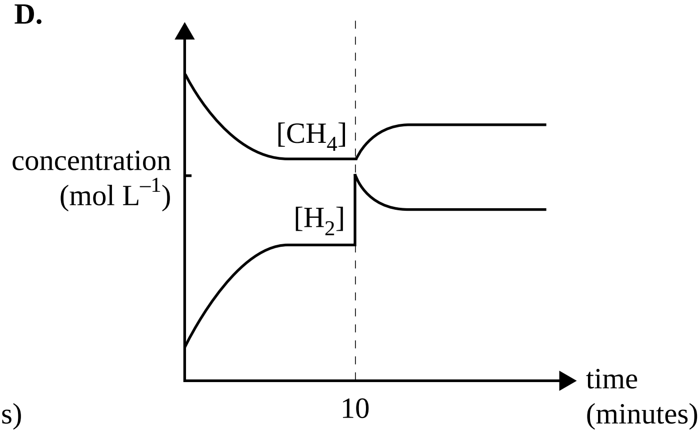


Question 4

The rate of a reaction generally increases with temperature.

The factor that has the **biggest effect** on the increase in reaction rate is that with increasing temperature

A. the activation energy of the reaction increases.

B. the activation energy of the reaction decreases.

C. the number of collisions between particles increases.

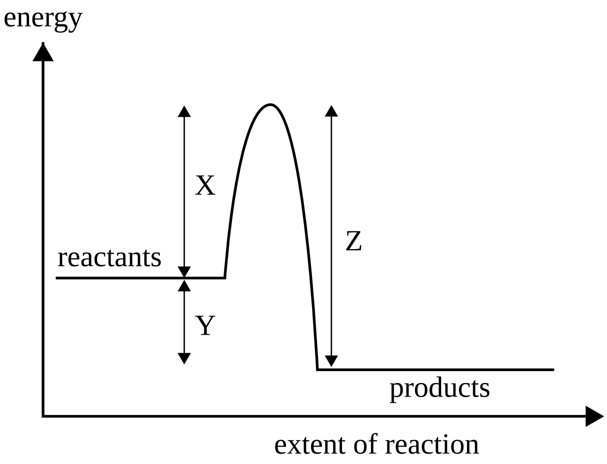
D. the proportion of particles with high kinetic energy increases.

Questions 5 and 6 refer to the following information.

The following reaction can occur to completion in aqueous solution.

$$CH_3Cl(aq) + OH^-(aq) \rightarrow CH_3OH(aq) + Cl^-(aq)$$

The energy change during this process is illustrated by



Question 5

A reaction can occur between a CH_3Cl molecule and a hydroxide ion

A. every time they collide.

B. only when they collide with exactly the energy X.

C. only when they collide with an energy equal to Y–Z.

D. only when they collide with an energy greater than or equal to energy X.

Question 6

A catalyst appropriate for this reaction will affect the value of

A. X only.

B. Y only.

C. X and Z only.

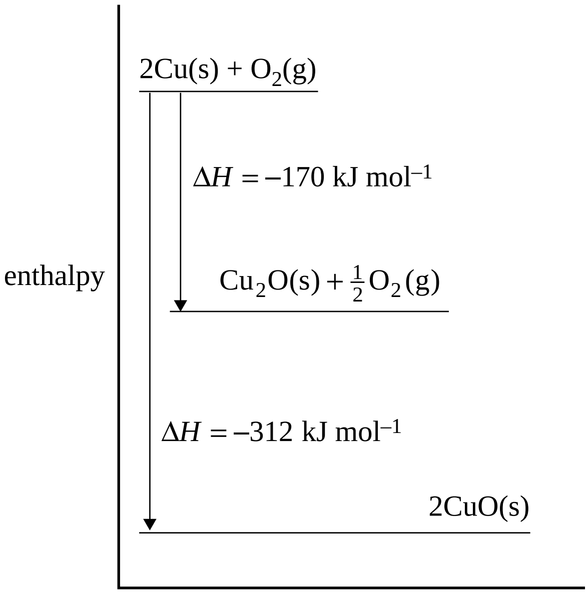
D. X, Y and Z.

Question 7

The following energy profile relates to the two reactions

$$2Cu(s) + O_2(g) \rightarrow 2CuO(s) \qquad \Delta H = -312 \text{ kJ mol}^{-1}$$

$$2Cu(s) + \tfrac{1}{2} O_2(g) \rightarrow Cu_2O(s) \qquad \Delta H = -170 \text{ kJ mol}^{-1}$$



The value of ΔH, in kJ mol^{-1}, for the reaction

$$4CuO(s) \rightarrow 2Cu_2O(s) + O_2(g)$$

is

A. +284

B. +142

C. –142

D. –284

Question 8

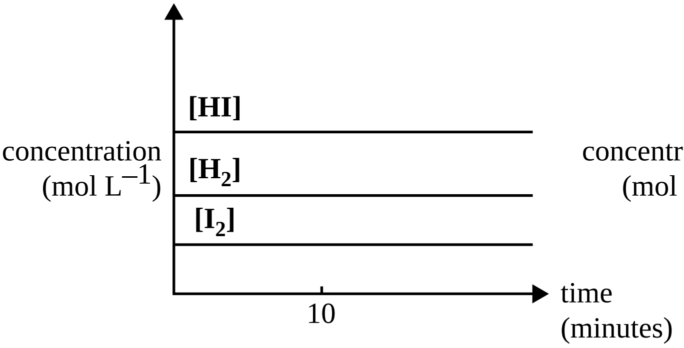
Hydrogen iodide dissociates into its elements according to the following equation.

$$2HI(g) \rightleftharpoons H_2(g) + I_2(g) \qquad \Delta H = +9 \text{ kJ mol}^{-1}$$

A mixture of $H_2(g)$, $I_2(g)$ and HI(g) rapidly comes to equilibrium in a 2.0 L container. After the reaction has been at equilibrium for 10 minutes, the volume of the container is suddenly reduced to 1.3 L at constant temperature.

Which one of the following graphs best represents the effect of this decrease in volume on the concentration of the gases in the mixture?

A.



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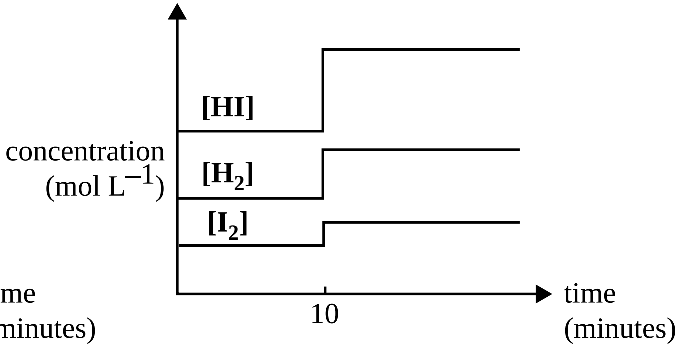
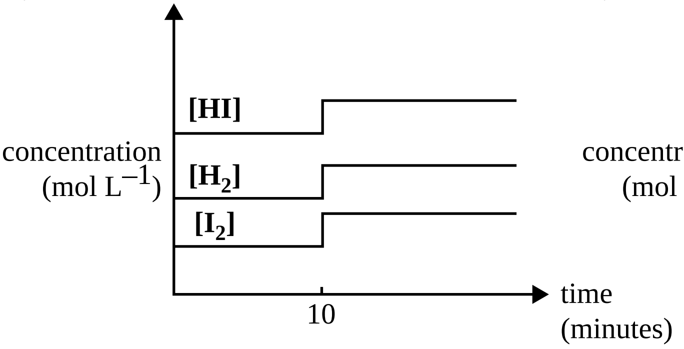
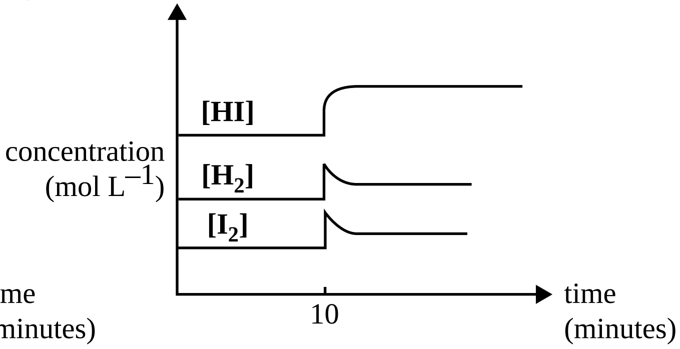


C.



D.



Questions 9 and 10 refer to the following information.

Phosphorus (V) chloride, PCl_5, decomposes to form phosphorus (III) chloride, PCl_3, and chlorine, Cl_2 according to the equation

$$PCl_5(g) \rightleftharpoons PCl_3(g) + Cl_2(g)$$

Question 9

Four different flasks, A, B, C and D, at the same temperature, contain a mixture of PCl_5, PCl_3 and Cl_2. The concentration, in mol L^{-1}, of these components in each of the flasks is shown below.

In three of the four flasks, the mixture of gases is at equilibrium.

In which one is the mixture of gases **not** at equilibrium?

Flask	**[PCl_5(g)]**	**[PCl_3(g)]**	**[Cl_2(g)]**
A.	0.15	0.20	0.30
B.	0.20	0.15	0.15
C.	0.10	0.10	0.40
D.	0.30	0.80	0.15

Question 10

Some gaseous PCl_5 is placed in an empty container.

When equilibrium is reached, the mass of the gas mixture, compared to the initial mass of PCl_5, is

A. halved.

B. unchanged.

C. one and a half times greater.

D. doubled.

Question 11

Gaseous NOCl decomposes to form the gases NO and Cl_2 according to the following equation.

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

The numerical value of the equilibrium constant for this reaction is 1.6×10^{-5} at 35°C.

What is the numerical value of the equilibrium constant, at 35°C, for the following reaction?

$$NO(g) + \tfrac{1}{2}Cl_2(g) \rightleftharpoons NOCl(g)$$

A. -1.6×10^{-5}

B. 1.6×10^{-5}

C. 2.5×10^{2}

D. 6.3×10^{4}

Question 12

The sodium salt of propanoic acid (sodium propanoate) is used as a preservative in bread and other baked goods. It can be produced by reacting propanoic acid with sodium hydroxide. In a particular experiment 100 mL of 0.080 M NaOH was added to 100 mL of 0.16 M propanoic acid.

Which of the following statements is/are correct?

I The pH of the resulting solution will be less than that of the propanoic acid solution.

II The resulting solution contains equal amounts of propanoic acid and its conjugate base.

III Before the NaOH was added there were no propanoate ions present.

A. II only

B. III only

C. I and II only

D. II and III only

Question 13

At the end of a particular experiment, a chemist was left with several materials to be disposed of in a safe manner. These included

i. 120 mL of ethyl ethanoate
ii. 150 mL unused 0.10 M NaCl
iii. a solid compound of lead that had been deposited on an electrode and then dried and weighed on filter paper.

Which one of the following alternatives describes an appropriate method of disposal of each of the above wastes from this experiment?

	120 mL ethyl ethanoate	**150 mL unused 0.10 M NaCl**	**Solid lead compound**
A.	waste container labelled 'ORGANIC LIQUIDS ONLY'	down the sink	waste container labelled 'DRY SOLIDS ONLY'
B.	waste container labelled 'ORGANIC LIQUIDS ONLY'	a stock bottle of 0.10 M NaCl prepared for the experiment	in the rubbish bin
C.	waste container labelled 'AQUEOUS WASTE ONLY'	waste container labelled 'AQUEOUS WASTE ONLY'	in the rubbish bin
D.	waste container labelled 'AQUEOUS WASTE ONLY'	a stock bottle of 0.10 M NaCl prepared for the experiment	waste container labelled 'DRY SOLIDS ONLY'

Question 14

A foam cup calorimeter containing 100 mL of water is calibrated by passing an electric current through a small heater placed in the solution.

Assuming that all measurements are accurate, which one of the following is the most likely calibration factor (in $J°C^{-1}$) for the calorimeter and contents?

A. 120
B. 240
C. 480
D. 960

Question 15

The numerical value of the heat of combustion of 1-propanol in $kJ\ g^{-1}$ is

A. 33.60
B. 2016
C. 3.360×10^4
D. 1.210×10^5

Question 16

When comparing the electrolysis of molten NaF and that of a 1.0 M aqueous solution of NaF, which one of the following statements is correct?

A. The product at the anodes is the same in both cells and the product at the cathodes is the same in both cells.
B. The product at the anodes is the same in both cells but the products at the cathodes are different.
C. The product at the cathodes is the same in both cells but the products at the anodes are different.
D. The products at the cathodes of the cells are different and also the products at the anodes are different.

Question 17

The following reactions occur spontaneously as written.

$$2Cr^{2+}(aq) + Co^{2+}(aq) \rightarrow 2Cr^{3+}(aq) + Co(s)$$

$$Co(s) + Pb^{2+}(aq) \rightarrow Co^{2+}(aq) + Pb(s)$$

$$Fe(s) + 2Cr^{3+}(aq) \rightarrow Fe^{2+}(aq) + 2Cr^{2+}(aq)$$

Using this information, predict which one of the following pairs of reactants will react spontaneously.

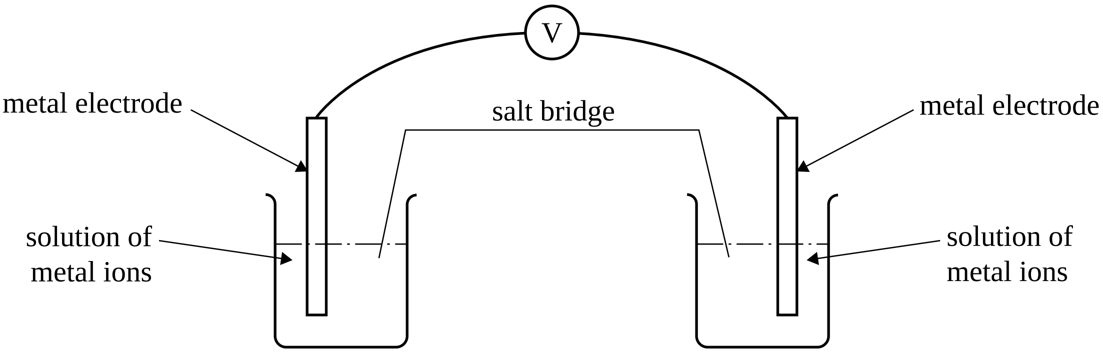
A. $Co(s) + Fe^{2+}(aq)$
B. $Cr^{2+}(aq) + Fe^{2+}(aq)$
C. $Cr^{2+}(aq) + Pb^{2+}(aq)$
D. $Pb(s) + Co^{2+}(aq)$

Question 18

Four half cells are constructed as follows.

Half cell I: an electrode of metal P in a 1.0 M solution of $P^+(aq)$ ions
Half cell II: an electrode of metal Q in a 1.0 M solution of $Q^+(aq)$ ions
Half cell III: an electrode of metal R in a 1.0 M solution of $R^+(aq)$ ions
Half cell IV: an electrode of Cu(s) metal in a 1.0 M solution of $Cu^{2+}(aq)$ ions

The half cells are connected in pairs, as shown below, to form a series of galvanic cells.



For each cell, the polarity of the electrodes and the voltage generated are recorded.

Half cells used	Positive electrode	Negative electrode	Voltage (V)
I and IV	P	Cu	0.46
II and IV	Cu	Q	0.57
III and IV	Cu	R	1.10
II and III	Q	R	0.53

Which one of the following alternatives lists the metals in order of **increasing** strength as reductants?

A. R, Q, Cu, P
B. Cu, P, Q, R
C. P, Cu, R, Q
D. P, Cu, Q, R

Question 19

Fuel cells are being developed that use fuels other than hydrogen as their energy sources. The table below shows four potential fuels and their reactions in the fuel cell. (For simplicity, symbols of state have been omitted from these reaction equations.)

Fuel		**Reaction in the fuel cell**
methanol	CH_3OH	$CH_3OH + H_2O \rightarrow CO_2 + 6H^+ + 6e^-$
ethanol	C_2H_5OH	$C_2H_5OH + 3H_2O \rightarrow 2CO_2 + 12H^+ + 12e^-$
ethane	C_2H_6	$C_2H_6 + 4H_2O \rightarrow 2CO_2 + 14H^+ + 14e^-$
ethane-1, 2-diol	$C_2H_4(OH)_2$	$C_2H_4(OH)_2 + 2H_2O \rightarrow 2CO_2 + 10H^+ + 10e^-$

Which one of the fuels would produce the greatest amount of CO_2 per coulomb of electrical charge generated?

A. methanol

B. ethanol

C. ethane

D. ethane-1, 2-diol

Question 20

Which one of the following, under standard conditions, can **not** be predicted from the electrochemical series?

A. Fe^{2+}(aq) is a stronger reductant than Br^-(aq).

B. Fe^{2+}(aq) is a stronger oxidant than Zn^{2+}(aq).

C. Sn^{2+}(aq) reacts faster with Ag^+(aq) than with Cu^{2+}(aq).

D. The equilibrium constant for the reaction between Sn^{2+}(aq) and Cu^{2+}(aq) is greater than the equilibrium constant for the reaction between Sn^{2+}(aq) and Zn^{2+}(aq).

END OF SECTION A

SECTION B – Short answer questions

Instructions for Section B

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

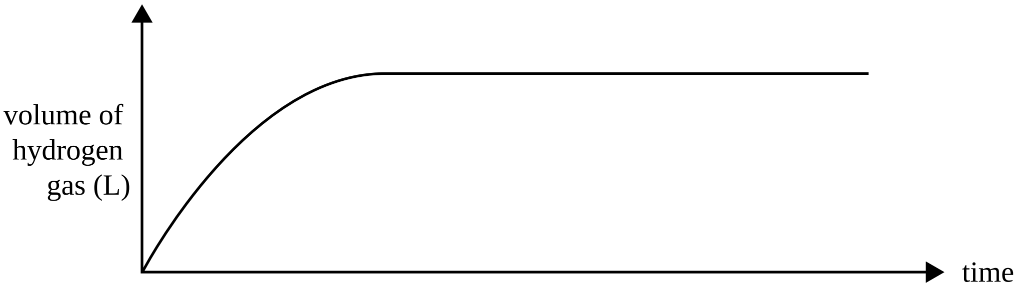
To obtain full marks for your responses you should

- 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 credit 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 2.0 g piece of magnesium ribbon was added to a known volume of 2.0 M hydrochloric acid. The volume of hydrogen gas produced during the reaction was measured and recorded.

The graph below shows the result of this experiment.



a. Write an equation for the reaction between magnesium and hydrochloric acid.

2 marks

b. In a second experiment, 2.0 g of magnesium **powder** was added to the same volume of 2.0 M hydrochloric acid as used in the first experiment.

On the axes above, sketch the expected graph of volume of hydrogen against time for this second experiment. Give an explanation for the shape of your graph.

2 marks

Total 4 marks

Question 2

Two experiments are carried out. Both involve the combustion of 2.09 g of ethanol.

a. **Experiment 1**

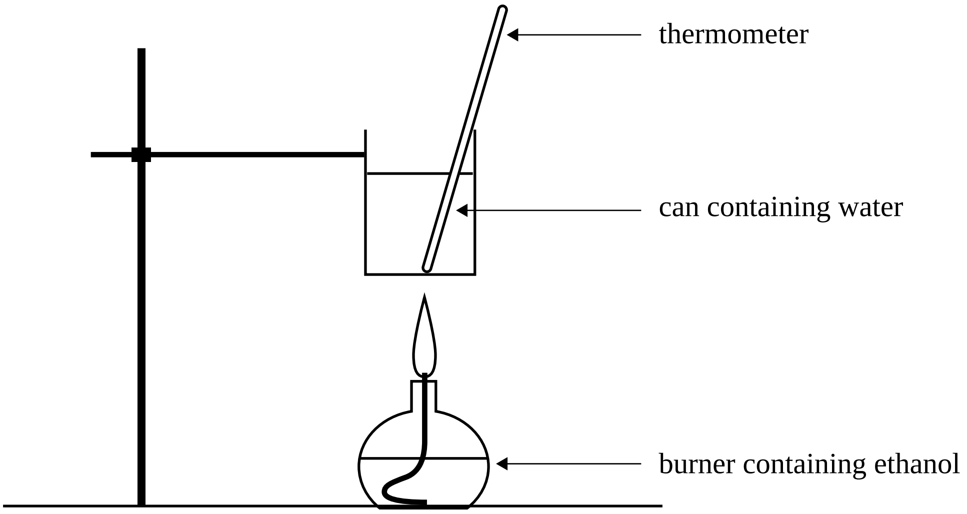
Ethanol is used to calibrate a bomb calorimeter. 2.09 g of ethanol is placed in the bomb calorimeter and reacted with excess oxygen. After the reaction is complete, the temperature of the water surrounding the bomb in the calorimeter has increased by 33.2°C.

Calculate, to an appropriate number of significant figures, the calibration factor of the calorimeter, in $kJ°C^{-1}$.

4 marks

b. **Experiment 2**

The same mass of ethanol is burnt to heat 200 g of water in a can as shown in the following diagram.



Initial temperature of water in the can: 25.3°C

Mass of water in the can: 200 g

Mass of ethanol burnt: 2.09 g

Calculate the final temperature of the water in the can. Assume that 60% of the heat from the burning ethanol is transferred to the water.

3 marks

Total 7 marks

Question 3

The following table lists the pH of 0.10 M solutions of four different acids at 25°C.

Acid	**pH**
I	1.0
II	3.0
III	0.7
IV	2.1

a. Which one of the four acids listed in the table above has the smallest K_a value?

1 mark

b. Which acid **must** have more than one acidic hydrogen per molecule? Give a reason for your answer.

2 marks

c. Using the concentration and the pH of acid IV, calculate the percentage ionisation of acid IV in the 0.10 M solution.

1 mark

d. Calculate the value of the ratio $[OH^-]_{acid\ II}/[OH^-]_{acid\ I}$ present in the solutions of acids II and I.

1 mark

e. Samples of the solutions of acids I and IV are diluted by a factor of 10.

The resulting **change in pH units** would be

(*Tick* ***one*** *of the following boxes.*)

greater for acid I than for acid IV	☐
greater for acid IV than for acid I	☐
the same for both acids	☐

Give an explanation for your answer.

2 marks

f. Methanoic acid is a weak monoprotic acid.

i. Calculate the concentration of a methanoic acid solution that will have the same pH as acid IV.

ii. The dissociation of methanoic acid in water is exothermic. If a solution of the acid is heated, will the pH of the solution **increase**, **decrease** or **remain constant**?

Give an explanation for your answer.

2 + 2 = 4 marks

Total 11 marks

Question 4

Dinitrogen tetroxide, N_2O_4(g), dissociates to form nitrogen dioxide, NO_2(g), according to the equation

$$N_2O_4(g) \rightleftharpoons 2NO_2(g)$$

0.45 mol of N_2O_4 gas is placed in an empty 1.00 L vessel at 100°C. When the system reaches equilibrium, there is 0.36 mol of NO_2 gas present in the vessel.

a. Calculate the numerical value of the equilibrium constant for this reaction at 100°C.

3 marks

b. At 25°C, the numerical value of the equilibrium constant for this reaction is 0.144.

Is this reaction endothermic or exothermic? Give an explanation for your answer.

2 marks

Total 5 marks

Question 5

The following chemicals are produced on an industrial scale in Australia.

ammonia ethene nitric acid sulfuric acid

a. Choose **one** only of these chemicals and circle its name in the left-hand column of the table below.

In the right-hand column, next to the chemical that you have chosen, circle **all** substances that can be used as raw materials in its production.

ammonia	H_2 N_2 O_2 CO_2 C_6H_{14} C_8H_{18} FeS_2 NH_3 SiO_2
ethene	H_2 N_2 O_2 CO_2 C_6H_{14} C_8H_{18} FeS_2 NH_3 SiO_2
nitric acid	H_2 N_2 O_2 CO_2 C_6H_{14} C_8H_{18} FeS_2 NH_3 SiO_2
sulfuric acid	H_2 N_2 O_2 CO_2 C_6H_{14} C_8H_{18} FeS_2 NH_3 SiO_2

1 mark

b. Write an equation for a reaction, in the industrial production of the chemical you have chosen, that is carried out **above** room temperature.

1 mark

c. Describe **one** way in which waste heat from the production of the chemical you have chosen is reused to reduce energy costs.

1 mark

d. **i.** Name **one** useful product formed from the chemical you have chosen.

ii. Write a chemical equation to show the formation of this product.

1 + 1 = 2 marks

Total 5 marks

Question 6

A research chemist is working on developing a catalytic electrode that makes possible the formation of methanol (CH_3OH) in an electrolytic cell using carbon dioxide from the air.

The electrode reactions in the electrolytic cell are

Cathode: $CO_2(g) + 6H^+(aq) + 6e^- \rightarrow CH_3OH(aq) + H_2O(l)$

Anode: $2H_2O(l) \rightarrow O_2(g) + 4H^+(aq) + 4e^-$

The aim of the research is to use electricity generated from a solar cell to produce the methanol. The resulting methanol could then be extracted and used as a fuel by burning it in air.

a. Give

i. a balanced equation for the complete combustion of methanol with oxygen

ii. the value in kJ mol^{-1}, and sign, of ΔH for the reaction you have written.

1 + 1 = 2 marks

b. A particular experimental electrolytic cell operates for 24.0 hours at a constant current of 25.5 A.

i. Calculate the amount of electricity, in coulomb, that passes through the cell.

ii. Calculate the mass, in grams, of methanol that forms during that time, assuming that all the electricity that passes through the cell is used to produce methanol.

In practice, it is found that less than the calculated amount of methanol is actually produced in this experiment.

iii. Given that the experimental readings of current, time and mass of methanol obtained are accurate, give one reason why the amount of methanol is lower than predicted.

1 + 3 + 1 = 5 marks

c. Predict the overall effect on atmospheric carbon dioxide levels of producing and then using, as an energy source, the methanol generated by this method. Justify your answer.

1 mark

Total 8 marks

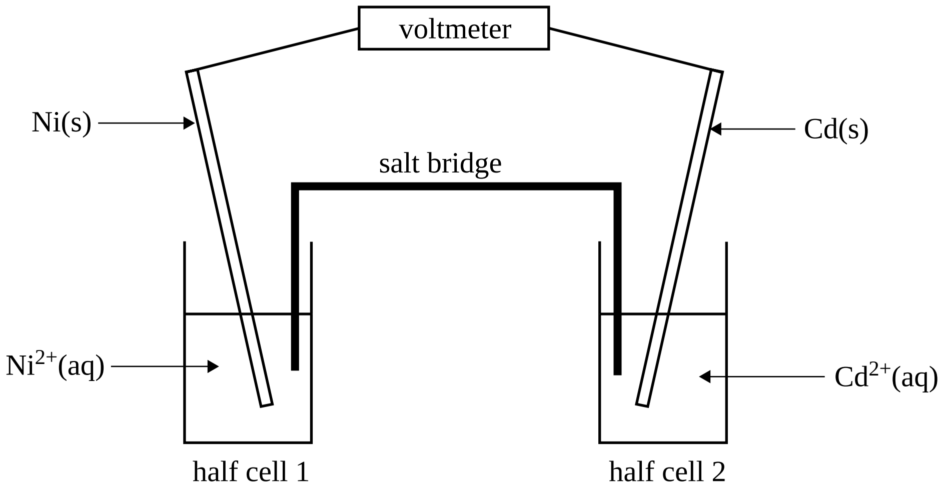
Question 7

a. A galvanic cell is constructed from the following two half cells under standard conditions.

Half cell 1: a nickel electrode in a solution of 1.0 M nickel nitrate

Half cell 2: a cadmium electrode in a solution of 1.0 M cadmium nitrate

A sketch of the cell is given below.



i. Given that the standard reduction potential of Cd^{2+}(aq)/ Cd(s) is –0.40V, show **on the above sketch** the direction in which electrons will flow in the external circuit of this galvanic cell.

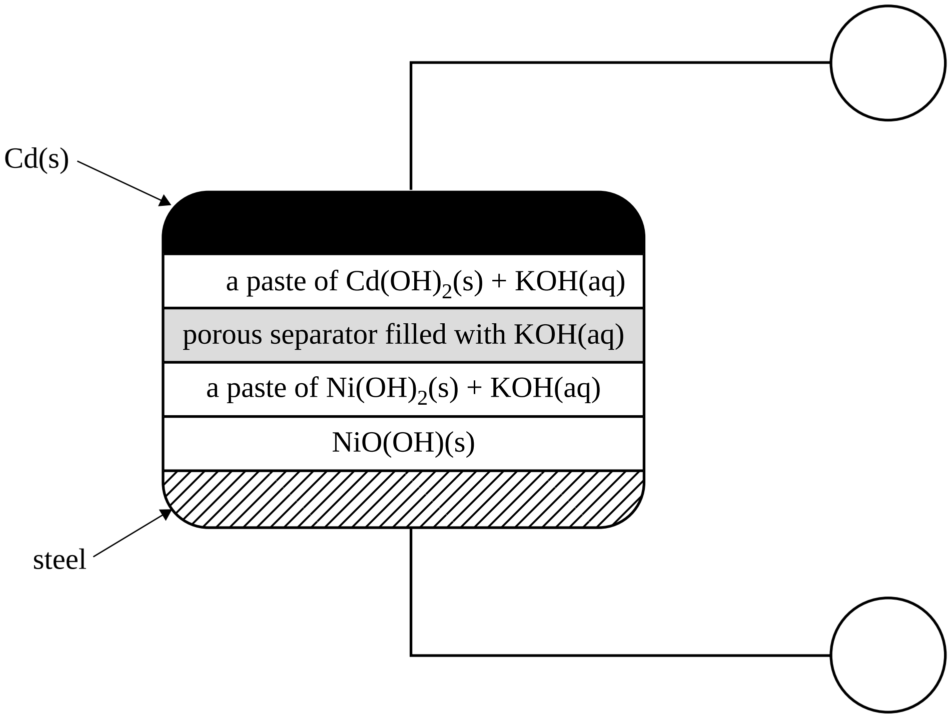
ii. Give the equation for the half reaction that takes place at the anode of this cell.

iii. List **two** factors that need to be considered when selecting an appropriate substance for use in the salt bridge.

1 + 1 + 2 = 4 marks

b. A rechargeable galvanic cell, also based on nickel and cadmium (NiCd cell), has been commercially available for a number of years and has been used to power small appliances such as mobile phones.

A simplified diagram of a NiCd cell is given below.



The overall cell reaction for the cell when discharging is

$$Cd(s) + 2NiO(OH)(s) + 2H_2O(l) \rightarrow Cd(OH)_2(s) + 2Ni(OH)_2(s)$$

i. Identify the positive and the negative electrodes by writing '+' or '–' in the circles provided in the diagram.

ii. What feature of this secondary cell enables it to be recharged?

iii. Give the equation for the half reaction that takes place at the negative electrode when the cell is discharging.

iv. Give the equation for the half reaction that takes place at the electrode connected to the negative terminal of the power supply when the cell is recharging.

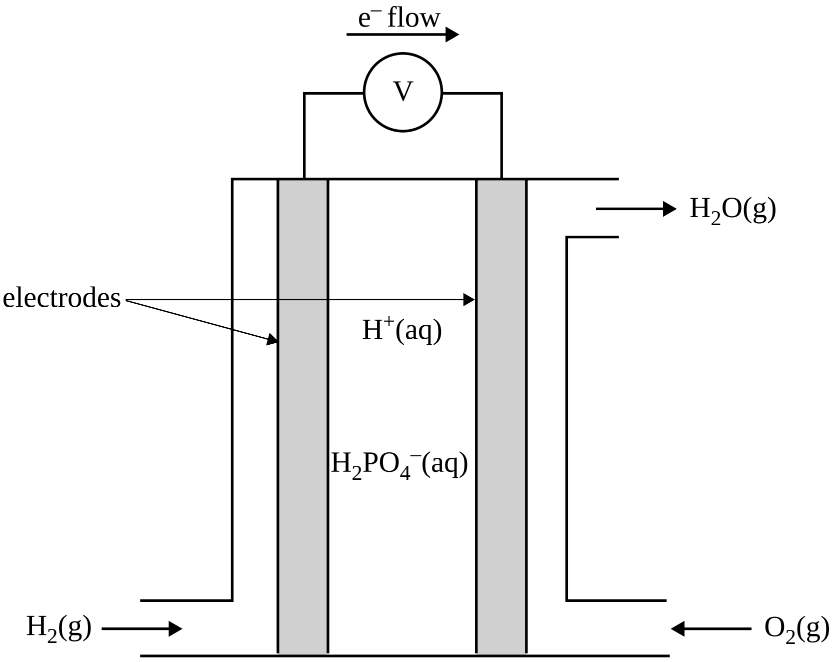
1 + 1 + 1 + 1 = 4 marks

Total 8 marks

Question 8

A fuel cell that can provide power for buses is the phosphoric acid fuel cell, PAFC. The electrolyte is concentrated phosphoric acid and the reactants are hydrogen and oxygen gases.

A simplified sketch of a phosphoric acid fuel cell is given below.



a. Give the equation for the half reaction that takes place at the

i. anode of this cell

ii. cathode of this cell.

1 + 1 = 2 marks

b. **On the diagram** of the fuel cell, draw an arrow to show the direction in which the $H_2PO_4^-$ ion moves as the cell delivers an electrical current.

1 mark

c. **i.** A particular cell operates at 0.92 V. How much energy, in kJ, is delivered per mole of hydrogen in this fuel cell?

ii. By comparing the energy delivered per mole of hydrogen in the fuel cell and the heat of combustion of hydrogen, calculate the energy efficiency of this fuel cell.

2 + 1 = 3 marks

d. Describe one advantage and one disadvantage of such a fuel cell compared with a petrol-driven car engine.

Advantage

Disadvantage

2 marks

Total 8 marks

Question 9

Since the start of the industrial age, most of the energy used by humans has come from the burning of coal and oil. In that time the amount of CO_2 in the air has increased from approximately 0.42% by mass to 0.58% by mass.

a. Assume that the total mass of the earth’s atmosphere is 5.15×10^{18} kg. Calculate the additional mass of CO_2, in kg, that has been added to the earth’s atmosphere since the start of the industrial age.

1 mark

b. If half of this additional CO_2 has come from the burning of coal, calculate the total amount of energy, in kJ, that has been produced by burning all this coal, given that

$$C(s) + O_2(g) \rightarrow CO_2(g); \quad \Delta H = -394 \text{ kJ mol}^{-1}$$

For the purposes of this calculation, assume that coal is pure carbon.

2 marks

Total 3 marks

END OF QUESTION AND ANSWER BOOK

VICTORIAN CURRICULUM AND ASSESSMENT AUTHORITY

Victorian Certificate of Education
2008

CHEMISTRY

Written examination

Thursday 13 November 2008

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

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

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

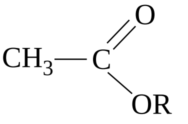
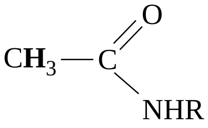
4. SI prefixes, their symbols and values

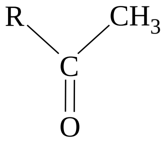
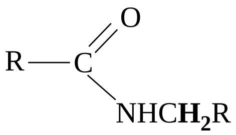
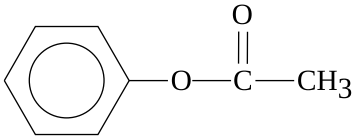
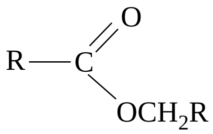
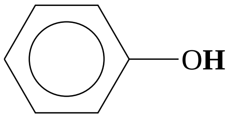
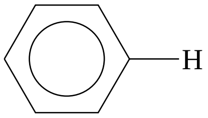
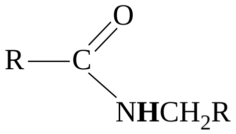
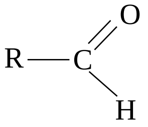
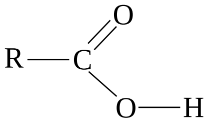
SI prefix	Symbol	Value
giga	G	10^9
mega	M	10^6
kilo	k	10^3
deci	d	10^{-1}
centi	c	10^{-2}
milli	m	10^{-3}
micro	μ	10^{-6}
nano	n	10^{-9}
pico	p	10^{-12}

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
 $CH_3–C(=O)OR$ or  $C\mathbf{H}_3–C(=O)NHR$	2.0

Type of proton	**Chemical shift (ppm)**
	2.1
$R{-}CH_2{-}X$ (X = F, Cl, Br or I)	3–4
$R{-}C\mathbf{H_2}{-}OH$	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
$RHC{=}C\mathbf{H}_2$	4.6–6.0
	7.0
	7.3
	8.1
	9–10
	11.5

6. ^{13}C NMR data

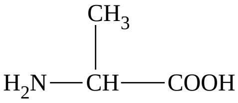
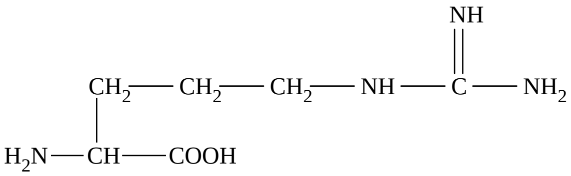
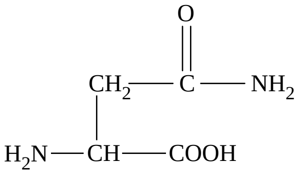
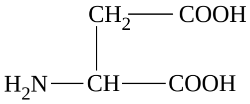
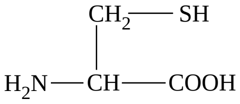
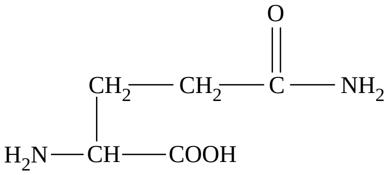
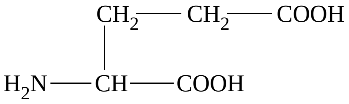
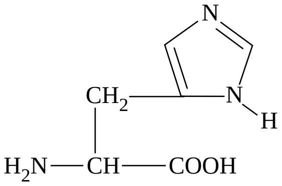
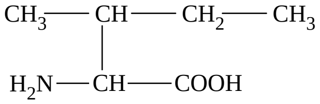
Type of carbon	Chemical shift (ppm)
$R–CH_3$	8–25
$R–CH_2–R$	20–45
$R_3–CH$	40–60
$R_4–C$	36–45
$R–CH_2–X$	15–80
$R_3C–NH_2$	35–70
$R–CH_2–OH$	50–90
RC≡CR	75–95
$R_2C=CR_2$	110–150
RCOOH	160–185

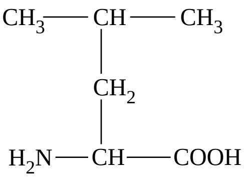
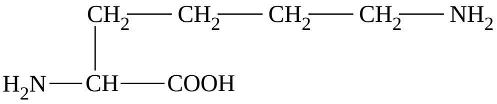
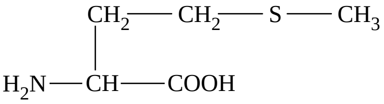
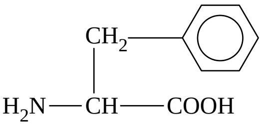
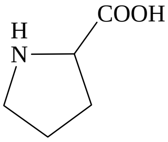
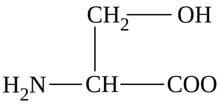
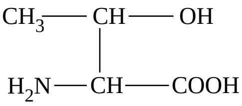
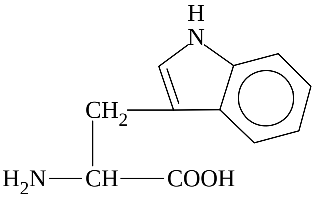
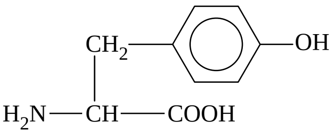
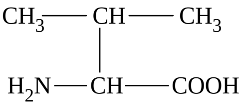
7. Infrared absorption data

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)

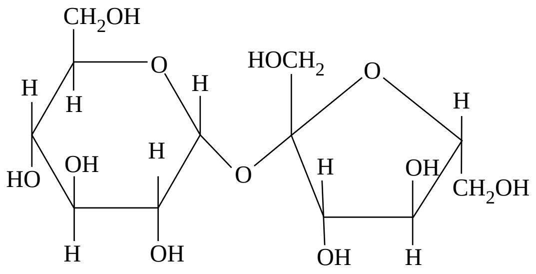
Name	**Symbol**	**Structure**
alanine	Ala	 $\begin{array}{rcl} & CH_3 & \\ & \vert & \\ H_2N- & CH & -COOH \end{array}$
arginine	Arg	 $\begin{array}{rcl} & CH_2-CH_2-CH_2-NH-\overset{NH}{\overset{\Vert}{C}}-NH_2 & \\ & \vert & \\ H_2N- & CH & -COOH \end{array}$
asparagine	Asn	 $\begin{array}{rcl} & CH_2-\overset{O}{\overset{\Vert}{C}}-NH_2 & \\ & \vert & \\ H_2N- & CH & -COOH \end{array}$
aspartic acid	Asp	 $\begin{array}{rcl} & CH_2-COOH & \\ & \vert & \\ H_2N- & CH & -COOH \end{array}$
cysteine	Cys	 $\begin{array}{rcl} & CH_2-SH & \\ & \vert & \\ H_2N- & CH & -COOH \end{array}$
glutamine	Gln	 $\begin{array}{rcl} & CH_2-CH_2-\overset{O}{\overset{\Vert}{C}}-NH_2 & \\ & \vert & \\ H_2N- & CH & -COOH \end{array}$
glutamic acid	Glu	 $\begin{array}{rcl} & CH_2-CH_2-COOH & \\ & \vert & \\ H_2N- & CH & -COOH \end{array}$
glycine	Gly	H_2N-CH_2-COOH
histidine	His	
isoleucine	Ile	 $\begin{array}{rcl} CH_3- & CH & -CH_2-CH_3 \\ & \vert & \\ H_2N- & CH & -COOH \end{array}$

Name	**Symbol**	**Structure**
leucine	Leu	 $CH_3—CH—CH_3$ CH_2 $H_2N—CH—COOH$
lysine	Lys	 $CH_2—CH_2—CH_2—CH_2—NH_2$ $H_2N—CH—COOH$
methionine	Met	 $CH_2—CH_2—S—CH_3$ $H_2N—CH—COOH$
phenylalanine	Phe	
proline	Pro	
serine	Ser	 $CH_2—OH$ $H_2N—CH—COOH$
threonine	Thr	 $CH_3—CH—OH$ $H_2N—CH—COOH$
tryptophan	Trp	
tyrosine	Tyr	
valine	Val	 $CH_3—CH—CH_3$ $H_2N—CH—COOH$

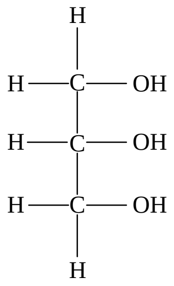
9. Formulas of some fatty acids

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	$C_{19}H_{31}COOH$

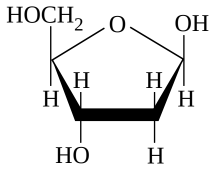
10. Structural formulas of some important biomolecules



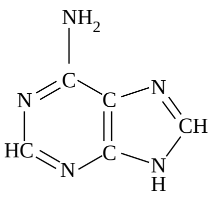
sucrose



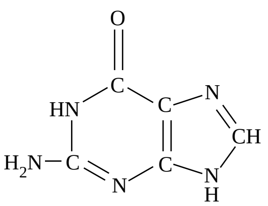
glycerol



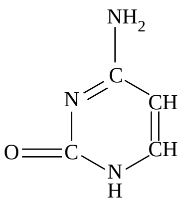
deoxyribose



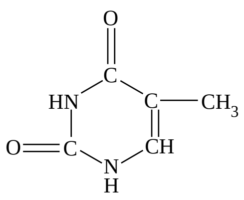
adenine



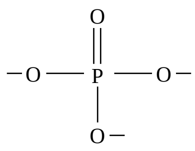
guanine



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}	1	–3509
hexane	C_6H_{14}	1	–4158
octane	C_8H_{18}	1	–5464
ethene	C_2H_4	g	–1409
methanol	CH_3OH	1	–725
ethanol	C_2H_5OH	1	–1364
1-propanol	$CH_3CH_2CH_2OH$	1	–2016
2-propanol	$CH_3CHOHCH_3$	1	–2003
glucose	$C_6H_{12}O_6$	s	–2816

END OF DATA BOOK