1995 VCE CHEMISTRY CAT 3

DETAILED SUGGESTED SOLUTIONS

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ã **CHEMISTRY ASSOCIATES 1997**

Directions to students

Materials
Question and answer booklet with a detachable data sheet. Working space is provided throughout this booklet. An approved calculator may be used.

The task
Detach the data sheet during reading time. Answer all questions. Questions should be answered in the spaces provided in this booklet. The marks allotted to each question are indicated at the end of the question. There is a total of 60 marks available. All written responses should be in English.

At the end of the task
Hand in the question and answer booklet.

There are 8 questions. Answer all questions.

To obtain full credit 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 credit
- show all working in your answers to numerical questions. No credit can 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 indications of state, for example H_2(g); NaCl (s).

Question 1

a. The digestion of food is catalysed by a very large number of different enzymes. Briefly explain why so many different enzymes are needed for the complete digestion of food.

b. The structure of a fat molecule sometimes consumed by humans is shown below.

CH_2 - 0 - CO - $(CH_2)_7CH{=}CH(CH_2)_7CH_3$
|
CH - 0 - CO - $(CH_2)_7CH{=}CH(CH_2)_7CH_3$
|
CH_2 - 0 - CO - $(CH_2)_7CH{=}CH(CH_2)_7CH_3$

i. What are two functions of the fat stored in our bodies?

ii. Briefly explain why fat molecules are almost insoluble in water.

iii. Draw diagrams showing the structure and bonding of the functional groups that are present in the molecules formed when the fat molecule shown in part **b.** is hydrolysed.

c. In a commercial food containing the fat shown in part b. opposite, an antioxidant has been added . Circle one structural feature of the molecule (shown opposite) that would be protected by the antioxidant.

(l + 6+ 1 =8 marks)

Question 1 (solution)

a. The complete digestion of food requires a very large number of chemical reactions. Enzymes are very specific in the catalysis of particular chemical reactions. One enzyme that works for one reaction will not work for another reaction. Hence, a very large number of different enzymes are needed.

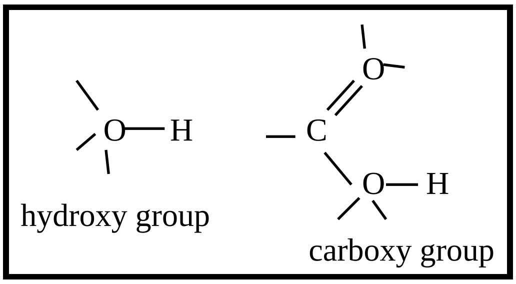
b. **i.** Fat is stored in our bodies as a source of energy , as heat and shock insulation, as physical support and as key chemicals for specific cell reactions such as cell membrane transportation and manufacture of steroids.

ii. Fat molecules are almost insoluble in water because they are have very little polarity (sections of the molecule which are either slightly positive or slightly negative) and, therefore, do not attract polar water molecules. Also, they cannot form hydrogen bonds with water molecules because all of the hydrogen atoms are attached to carbon atoms

iii. When this fat molecule is hydrolysed (reacted with water in the presence of enzymes), glycerol and the mono-unsaturated fatty acid, oleic acid, are produced as shown in the reaction below.

$$\text{fat} + H_2O \rightarrow \underset{\text{glycerol}}{C_3H_5(OH)_3} + \underset{\text{oleic acid}}{3\ CH_3(CH_2)_7CH{=}CH(CH_2)_7COOH}$$

The functional groups involved are -OH and -COOH with the structures:

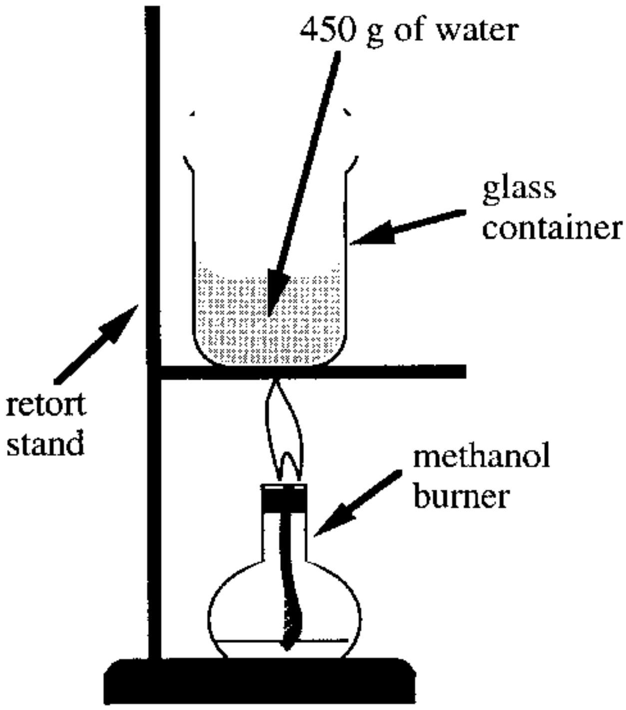


c. An antioxidant (as the name implies) is added to the fat to prevent the oxidation of the fat (reaction with oxygen) . The double bond in oleic acid is quite reactive. Circle any one of the double bonds (=) in

$CH_2 - 0 - CO - (CH_2)_7CH{=}CH(CH_2)_7CH_3$
|
$CH - 0 - CO - (CH_2)_7CH{=}CH(CH_2)_7CH_3$
|
$CH_2 - 0 - CO - (CH_2)_7CH{=}CH(CH_2)_7CH_3$

Question 2

An experiment was performed by a student to determine an approximate value of the heat of combustion of methanol (CH_30H). The apparatus was set up as shown below.



It required 1.1 0 g of methanol to be burnt to raise the temperature of 450 g of water by 9.9 ^oC.

a. Use the experimental data given to calculate a value of the heat of combustion per mole of methanol given that the heat capacity of water is 4.18 J $^oC^{-1}$ g^{-1}.

b. The correct value of the heat of combustion of methanol is 725 kJ mol^{-1}, a value considerably greater than the value you should have obtained from your calculation in part **a.** Suggest, and briefly justify, two simple changes to the experimental design that might lead to an experimental result closer to the 'correct' value. If you wish, you may use a simple diagram to show your suggested modifications.

(5+ 2=7 marks)

Question 2 (solution)

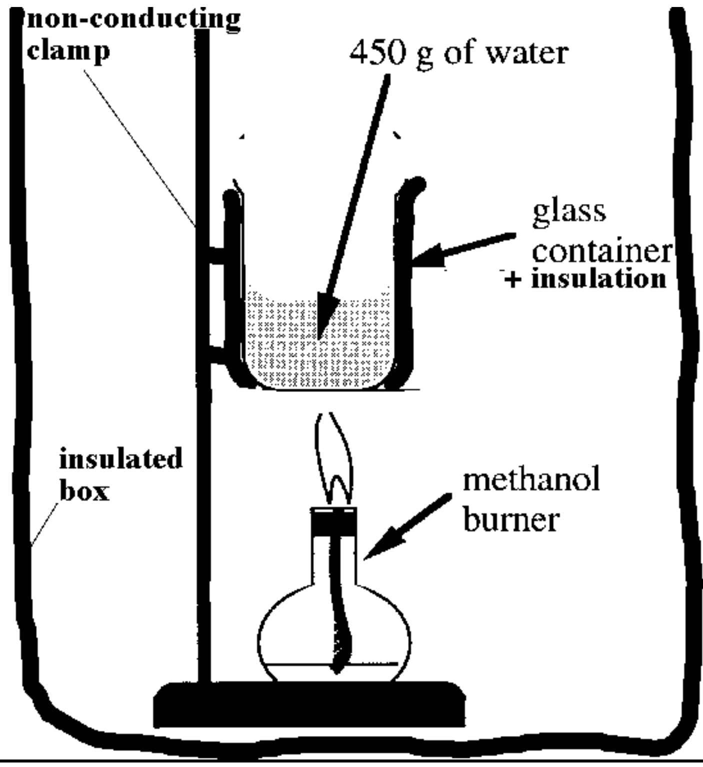
a. Energy used to heat the water = (450 g x 9.9 ^{o}C x 4.18 J $^{o}C^{-1}$ g^{-1}) J = 18621.9 J

Assuming that all the energy supplied by methanol was used to heat the water,

1.10 g of methanol produces 18621.9 J
32 g (1 mole) of methanol produces ?

Heat of combustion of methanol = $\frac{18621.9 \times 32}{1.1}$ = 541728 J = 542 kJ mol^{-1} **ANS**

b. The difficulty with the experimental design is that a considerable proportion of the heat energy produced from the combustion of the methanol is lost to the surroundings instead of being used to heat the water.
To prevent this loss of energy, the glass beaker should have insulation around the sides, the retort stand should be replaced by a non-conducting holder and the whole apparatus should be placed inside a large non-flammable box to keep air movement to a minimum. This is shown in the diagram below.



Question 3

Most of the molecules A to H shown below are biologically important.

$NH_2CH_2CH_2COOH$	NH_2CH_2COOH	$C_3H_8O_3$	$C_{18}H_{34}O_2$
A	**B**	**C**	**D**
NH_2CONH_2	$C_6H_{12}O_6$	$C_{18}H_{36}O_2$	CH_3COOH
E	**F**	**G**	**H**

Identify the molecule or molecules from the set above that could have been formed by the hydrolysis of:

Cellulose	**A**	**B**	**C**	**D**	**E**	**F**	**G**	**H**
Protein	**A**	**B**	**C**	**D**	**E**	**F**	**G**	**H**
An unsaturated fat	**A**	**B**	**C**	**D**	**E**	**F**	**G**	**H**
Starch	**A**	**B**	**C**	**D**	**E**	**F**	**G**	**H**
A saturated fat	**A**	**B**	**C**	**D**	**E**	**F**	**G**	**H**

Give your answer by circling the appropriate letter or letters in each case.

(5 marks)

Question 3 (solution)

A and **B** are amino acids, **C** is glycerol, **D** is an unsaturated fatty acid, **E** is urea, **F** is a monosaccharide (for example, glucose), **G** is a saturated fatty acid, **H** is acetic acid

When cellulose is hydrolysed, monosaccharides, $C_6H_{12}O_6$, are produced. **F**

When a protein is hydrolysed, amino acids are produced. **A** and **B**

When an unsaturated fat is hydrolysed, glycerol and an unsaturated fatty acid are produced. **C** and **D**

When starch is hydrolysed, monosaccharides, $C_6H_{12}O_6$, are produced. **F**

When a saturated fat is hydrolysed, glycerol and a saturated fatty acid are produced. **C** and **G**

Question 4

a. The nature of atomic nuclei can be represented in the form $^{\mathbf{A}}_{\mathbf{Z}}\mathbf{E}$,

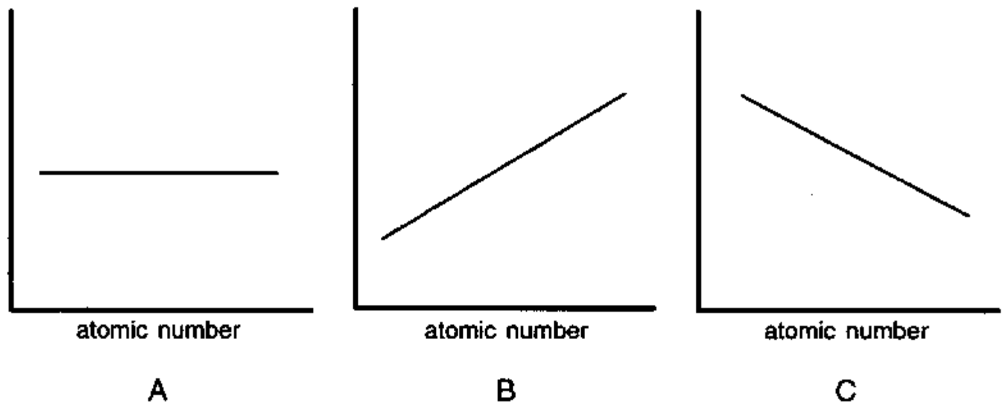
where **E** is the symbol for the element.

i. What does the symbol **A** represent?
ii. What does the symbol **Z** represent?
iii. Complete the following nuclear equation by writing correct numerical values in the boxes provided.

$$^{1}_{0}n + ^{235}_{92}U \rightarrow ^{\square}_{56}Ba + ^{92}_{\square}Kr + 3^{1}_{0}n + \text{energy}$$

b. **i.** Give the electronic structure of the atom of atomic number 14.
ii. In which group of the periodic table is the element whose atoms have an atomic number of 14?

c. The following graphs show how certain properties vary either across a period or down a group of the periodic table.



Select from **A**, **B** and **C** above, the graph which would best represent the trend in each of the following properties.

i. atomic radii of Li, Na, K, Rb
ii. electronegativities of C, N, O, F
iii. number of electrons in F^{-}, Ne, Na^{+}, Mg^{2+}
iv. first ionisation energies of Li, Na, K, Rb

d. The oxides of the elements across a period show a trend in acid-base properties. Write balanced equations for each of the following reactions.

Sodium oxide, Na_2O, with water
Aluminium oxide, Al_2O_3, with excess hydrogen ions
Aluminium oxide, Al_20_3, with excess hydroxide ions
Sulfur trioxide, SO_3, with excess hydroxide ions

(4+ 2+ 4+ 4 = 14 marks)

Question 4 (solution)

a. **i.** The symbol A represents the mass number
- the total number of protons plus neutrons in the nucleus

ii. The symbol Z represents the atomic number - the number of protons in the nucleus.

iii.

$$^{1}_{0}n + ^{235}_{92}U \rightarrow \boxed{^{141}_{56}}Ba + \boxed{^{92}_{36}}Kr + 3^{1}_{0}n + \text{energy}$$

b. **i.** An atom with atomic number 14 has 14 electrons.
The electronic structure is $1s^2\ 2s^2\ 2p^6\ 3s^2\ 3p^2$.

ii. Element 14 is silicon in group IV of the Periodic Table.

c. **i.** Within group I in the Periodic Table, the atomic radii increase as the atomic number increases. **ANS B**

ii. Within period II in the Periodic Table, the electronegativities increase as the atomic number increases. **ANS B**

iii. The number of electrons in each of these ions is 10. The number of electrons is constant as the atomic number increases. **ANS A**

iv. Within group I in the Periodic Table, the first ionization energies decrease as the atomic number increases. **ANS C**

d. $Na_2O(s) + H_2O(l) \rightarrow 2NaOH(aq)$

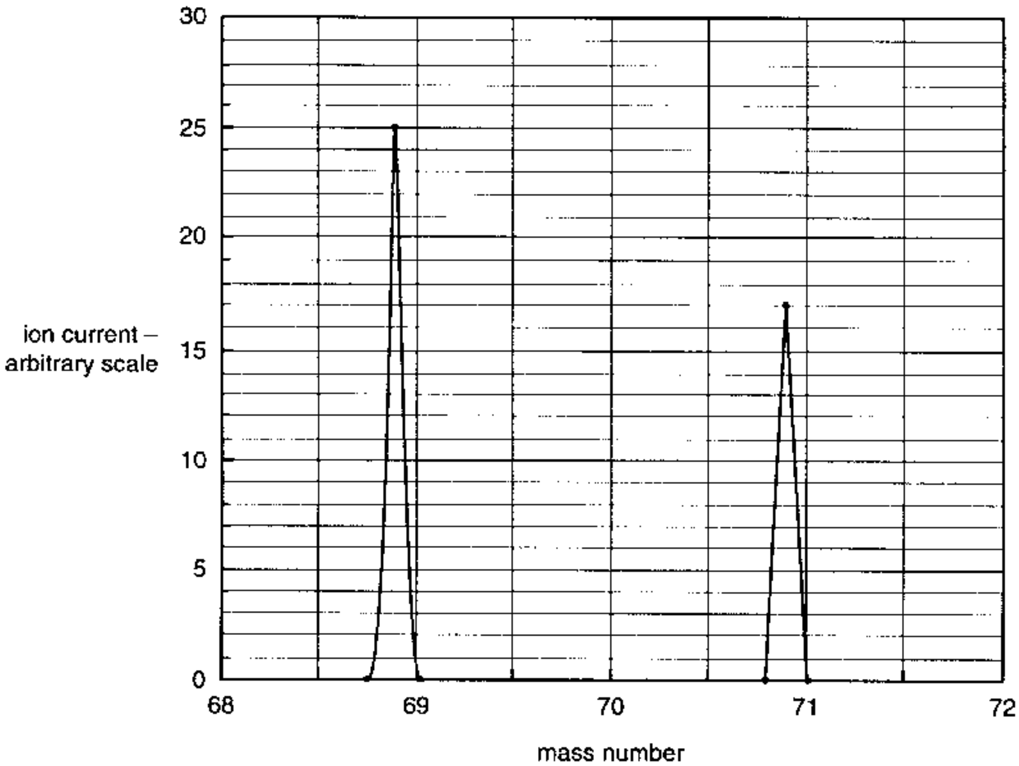
$Al_2O_3(s) + 6H^+(aq) \rightarrow 2Al^{3+}(aq) + 3H_2O(l)$

$Al_2O_3(s) + 6OH^-(aq) \rightarrow 2Al(OH)_3(s)$ and then,
$Al(OH)_3(s) + OH^-(aq) \rightarrow Al(OH)_4^-(aq)$

$SO_3(g) + 2OH^-(aq) \rightarrow SO_4^{2-}(aq) + H_2O(l)$

Question 5

A sample of gallium metal was vaporised and the vapour introduced into the ionisation chamber of a mass spectrometer. The resultant mass spectrum is illustrated below and shows two peaks, one of isotopic mass 68.9 and the other of isotopic mass 70.9.



a. What causes the ionisation of the gallium metal vapour in the ionisation chamber of the mass spectrometer?

b. Use the data shown in the graph to calculate the percentage abundance of each of the isotopes.

c. Use the percentage abundances you have calculated in part **b.** to calculate a value of the relative isotopic mass of gallium.

(1 +2+ 2=5 marks)

Question 5 (solution)

a. The ionisation of the gallium metal vapour is caused by bombarding the gallium metal atoms with electrons in a low pressure chamber. This results in the formation of positive ions (mainly with one positive charge)

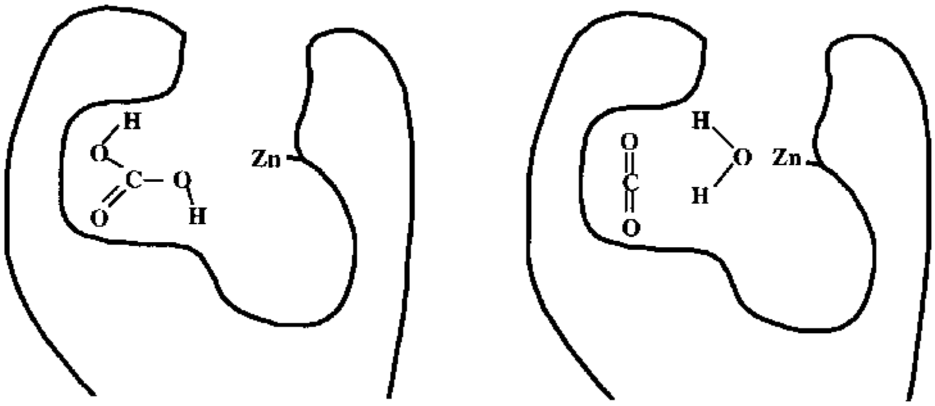
b. % abundance of isotope with mass 68.9 = $\frac{25}{25 + 17}$ x 100 = $\frac{25}{42}$ x 100 = 59.5 % **ANS**

% abundance of isotope with mass 70.9 = $\frac{17}{25 + 17}$ x 100 = $\frac{17}{42}$ x 100 = 40.5 % **ANS**

c. Relative Isotopic Mass = ($\frac{59.5}{100}$ x 68.9) + ($\frac{40.5}{100}$ x 70.9) = 40.9955 + 28.7145 = 69.7 **ANS**

Question 6

An important enzyme-catalysed reaction is the dehydration of the molecule carbonic acid to carbon dioxide and water by the zinc-containing enzyme, carbonic anhydrase. This reaction is a step in the removal from the body of CO_2, a product of the oxidation of glucose. The reaction in the enzyme is shown in a diagrammatic form below.



carbonic acid held in position in the enzyme prior to decomposition

carbon dioxide and water immediately following decomposition of carbonic acid

a. Carbonic acid, H_2CO_3, is formed when the hydrogen carbonate ion reacts with a hydrogen ion. Write a chemical equation for this process.

b. What is meant by the 'primary structure' of an enzyme?

c. What is meant by the 'secondary structure' of an enzyme and how is the secondary structure maintained?

d. By referring to the diagram shown above, explain how the tertiary structure of an enzyme determines its function.

e. Holding carbonic anhydrase at a temperature of $60^{O}C$ causes it to become denatured and thus ineffective in catalysing the dehydration of carbonic acid. Yet the primary structure of the enzyme remains unaffected. Give a probable explanation of why the enzyme has ceased to be effective.

(1 + 1 + 2 + 2 + 1 = 7 marks)

Question 6 (solution)

a. The chemical equation is: $HCO_3^-(aq) + H^+(aq) \rightarrow H_2CO_3(aq)$

b. An enzyme is a protein. The primary structure is the sequence of amino acids in the protein chain.

c. The secondary structure of the enzyme is the coiling and folding of the chain of amino acids caused by the attraction between parts of the chain. The secondary structure is maintained by some form of chemical bonding, for example, hydrogen bonding between -CO and -NH groups of neighbouring amino acid units.

d. The tertiary structure of an enzyme is its overall three dimensional shape caused by chemical bonding between different parts of the chain. This bonding can be ionic, covalent or hydrogen bonding. It is this tertiary structure which determines the catalytic activity of the enzyme. In this example, the Zn atom comes into close contact with the H_2CO_3 (because of the unique shape of the tertiary structure) and a reaction occurs.

e. The enzyme has ceased to be effective because the high temperature has caused the breakup of the tertiary structure of the enzyme. When the tertiary structure disappears, the catalytic activity is lost.

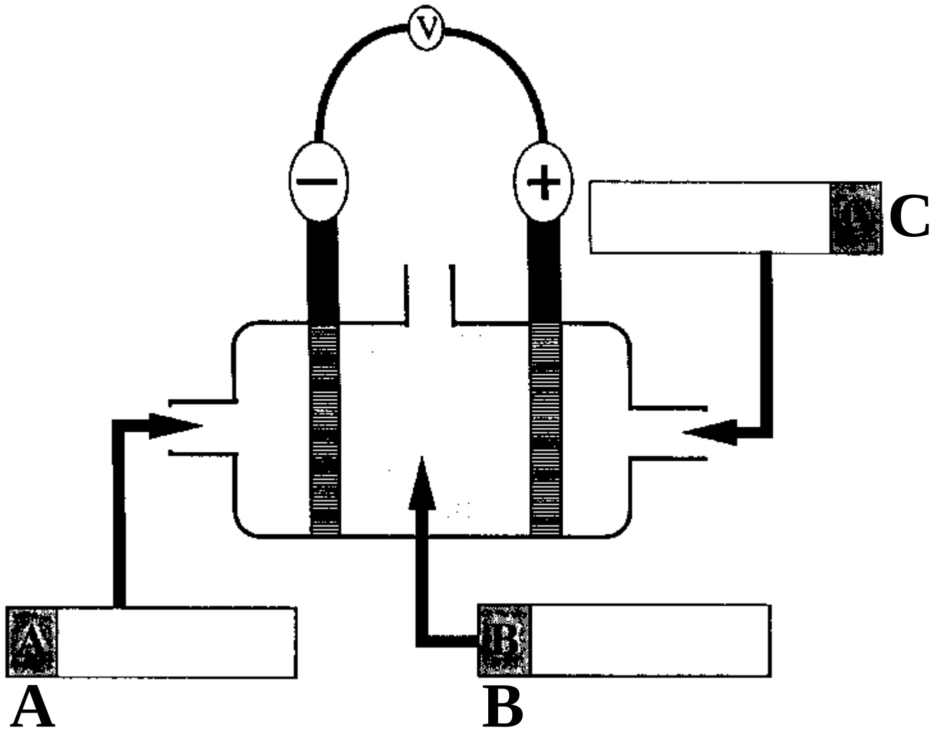
Question 7

The hydrogen-oxygen fuel cell has been used as an energy source in many spacecraft. The two half reactions are:

$$O_2(g) + 2H_2O(l) + 4e^- \rightarrow 40H^-(aq)$$

$$H_2(g) + 20H^-(aq) \rightarrow 2H_2O(l) + 2e^-$$

a. An incomplete diagram of a cell that uses an alkaline electrolyte is given below.



Question 7 (continued)

i. Write the formulas of possible chemical species for **A**, **B** and **C** in the boxes provided beside the letters.

ii. Indicate on the diagram the direction of electron flow.

b. Write a balanced overall equation for the cell reaction.

c. Briefly describe two important functions of the electrodes in this cell.

(4 + 1 + 2 = 7 marks)

Question 7 (solution)

a. i. The polarity of the cell is caused by the chemical reaction. At the negative electrode, electrons are being produced. Hence, hydrogen gas must be reacting here.

A = H_2(g) ANS

At the positive electrode, electrons are being used up.
Hence, oxygen gas must be reacting here.

C = O_2(g) ANS

The alkaline electrolyte between the two electrodes could be potassium hydroxide (KOH)

B = KOH ANS

ii. Electrons will flow from the negative electrode to the positive electrode through the voltmeter

b. The balanced overall equation for the cell reaction can be obtained by multiplying the hydrogen gas equation by 2 to balance the electrons at 4 electrons and then adding this equation to the oxygen gas equation as shown below.

$$O_2(g) + 2H_2O(l) + 4e^- \rightarrow 40H^-(aq)$$

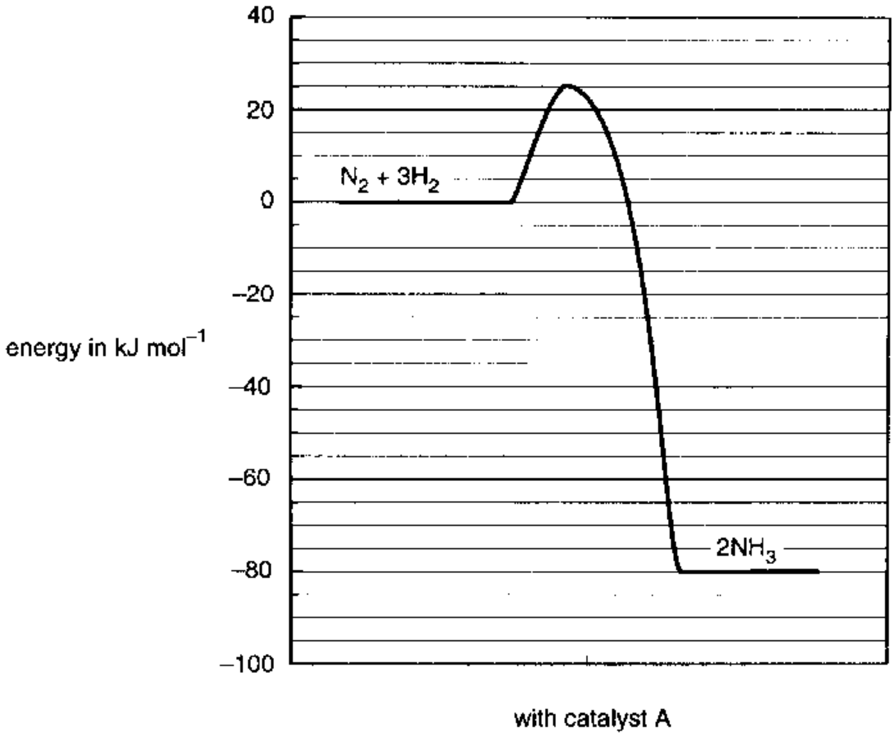
$$(H_2(g) + 20H^-(aq) \rightarrow 2H_2O(l) + 2e^-) \times 2$$

$$2H_2(g) + O_2(g) \rightarrow 2H_2O(l)$$

c. The functions of the electrodes in the fuel cell are:
(1) to act as catalysts for the electrode reaction
(2) to act as conductors for the current produced
(the surface area of the electrodes determines the size of the current produced)

Question 8

An energy profile is shown below for the reaction: $N_2(g) + 3H_2(g) \Leftrightarrow 2NH_3(g)$
in the presence of a particular catalyst, identified as 'catalyst A'.



a. Give the value and sign of the ΔH of the forward reaction.

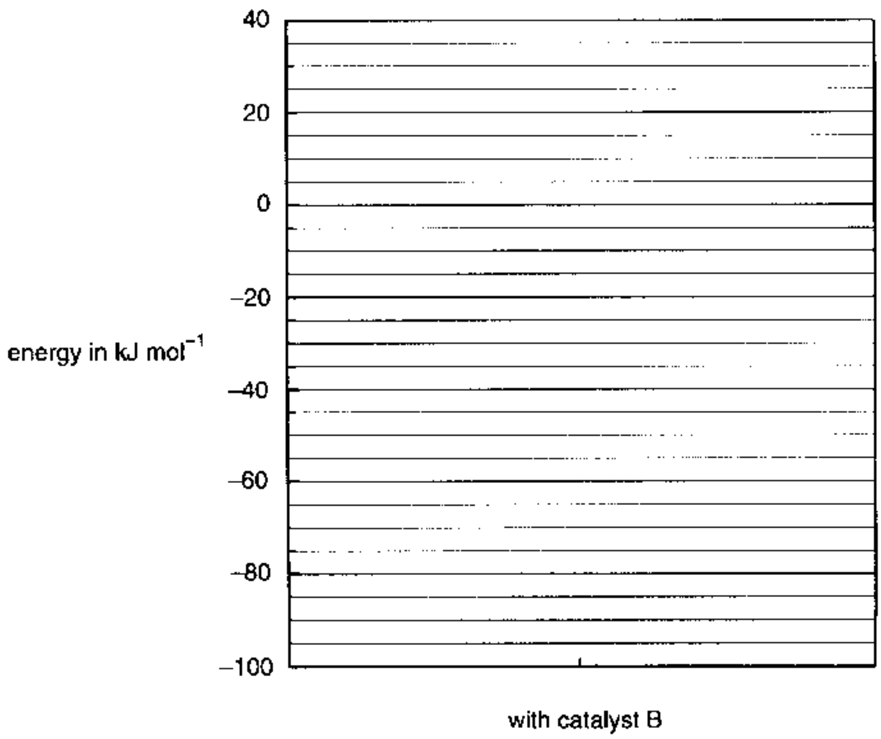
b. Give the value and sign of the activation energy of the forward reaction.

c. Give the value and sign of the ΔH of the reverse reaction.

d. Give the value and sign of the activation energy of the reverse reaction.

Question 8 (continued)

e. **Catalyst A** is removed and is replaced with **catalyst B**, a more effective catalyst that makes the reaction go faster. Sketch on the blank graph below a possible form of the energy profile for the same reaction in the presence of **catalyst B**.



(1 + 1 + 1 + 1 + 3 = 7 marks)

Question 8 (solution)

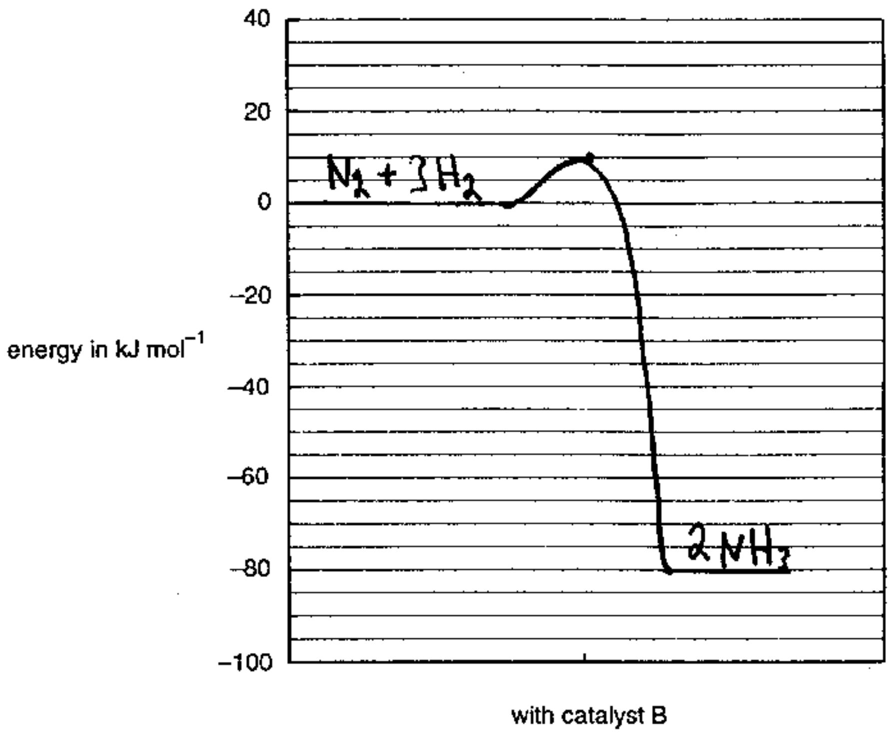
a. ΔH of the forward reaction = H (products) - H (reactants) = - 80 - 0 = - 80 kJ mol^{-1} **ANS**

b. The activation energy of the forward reaction is the 'energy barrier' to the reaction = 25 - 0 = + 25 kJ mol^{-1} **ANS**

c. ΔH of the reverse reaction = H (products) - H (reactants) = 0 - (-80) = + 80 kJ mol^{-1} **ANS**

d. The activation energy of the reverse reaction is the 'energy barrier' to the reaction = 25 - (-80) = + 105 kJ mol^{-1} **ANS**

e. A more effective catalyst does not change the position of equilibrium. It does lower the activation energy of both the forward and the reverse reactions. That is, the new activation energies must be less than 25 kJ mol^{-1} and 105 kJ mol^{-1} for the forward and the reverse reactions respectively. One possible energy profile is shown below.



END OF SUGGESTED SOLUTIONS

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Chemistry CAT 3

Data Sheet

Physical constants

$F = 96\,500 \text{ C mol}^{-1}$

The electrochemical series

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

Periodic table of the elements

1 **H** 1.0																	2 **He** 4.0
3 **Li** 6.9	4 **Be** 9.0											5 **B** 10.8	6 **C** 12.0	7 **N** 14.0	8 **O** 16.0	9 **F** 19.0	10 **Ne** 20.1
11 **Na** 23.0	12 **Mg** 24.3											13 **Al** 27.0	14 **Si** 28.1	15 **P** 31.0	16 **S** 32.1	17 **Cl** 35.5	18 **Ar** 39.9
19 **K** 39.1	20 **Ca** 40.1	21 **Sc** 44.9	22 **Ti** 47.9	23 **V** 50.9	24 **Cr** 52.0	25 **Mn** 54.9	26 **Fe** 55.8	27 **Co** 58.9	28 **Ni** 58.7	29 **Cu** 63.5	30 **Zn** 65.4	31 **Ga** 69.7	32 **Ge** 72.6	33 **As** 74.9	34 **Se** 79.0	35 **Br** 79.9	36 **Kr** 83.8
37 **Rb** 85.5	38 **Sr** 87.6	39 **Y** 88.9	40 **Zr** 91.2	41 **Nb** 92.9	42 **Mo** 95.9	43 **Tc** 98.1	44 **Ru** 101.1	45 **Rh** 102.9	46 **Pd** 106.4	47 **Ag** 107.9	48 **Cd** 112.4	49 **In** 114.8	50 **Sn** 118.7	51 **Sb** 121.8	52 **Te** 127.6	53 **I** 126.9	54 **Xe** 131.3
55 **Cs** 132.9	56 **Ba** 137.3	57 **La** 138.9	72 **Hf** 178.5	73 **Ta** 180.9	74 **W** 183.8	75 **Re** 186.2	76 **Os** 190.2	77 **Ir** 192.2	78 **Pt** 195.1	79 **Au** 197.0	80 **Hg** 200.6	81 **Tl** 204.4	82 **Pb** 207.2	83 **Bi** 209.0	84 **Po** (209)	85 **At** (210)	86 **Rn** (222)
87 **Fr** (223)	88 **Ra** (226)	89 **Ac** (227)															

Lanthanides

58 **Ce** 140.1	59 **Pr** 140.9	60 **Nd** 144.2	61 **Pm** (145)	62 **Sm** 150.4	63 **Eu** 152.0	64 **Gd** 157.2	65 **Tb** 158.9	66 **Dy** 162.5	67 **Ho** 164.9	68 **Er** 167.3	69 **Tm** 168.9	70 **Yb** 173.0	71 **Lu** 175.0

Actinides

90 **Th** 232.0	91 **Pa** 231.0	92 **U** 238.0	93 **Np** 237.1	94 **Pu** (244)	95 **Am** (243)	96 **Cm** (247)	97 **Bk** (247)	98 **Cf** (251)	99 **Es** (254)	100 **Fm** (257)	101 **Md** (258)	102 **No** (255)	103 **Lr** (256)