VCE CHEMISTRY
2009

UNIT 4
TRIAL
EXAMINATION
SUGGESTED
SOLUTIONS

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Question 1 **ANS A**

The equilibrium constant is very large. NO will react with O_2 to produce more NO_2. More NO will be used up than O_2 since they react in a ratio of 2 : 1. Hence, NO will have the lowest concentration at equilibrium and NO_2 will have the highest concentration at equilibrium.
Let *x* be the number of mol of O_2 reacting.
The value of x could be calculated from the equilibrium expression :

$$K_c = \frac{(1+2x)^2}{(1-2x)^2(1-x)} = 6.6 \times 10^5$$

Question 2 **ANS C**

The forward reaction is exothermic. Therefore, a decrease in temperature will shift the equilibrium position to the right and increase the value of the equilibrium constant. Decreasing the volume of the container to 0.5 L will shift the position of equilibrium to the right but the value of the equilibrium constant will not change.

Question 3 **ANS B**

For the original equation $2NO(g) + O_2(g) \rightleftharpoons 2NO_2(g)$,

the equilibrium constant = $K_1 = \dfrac{[NO_2]^2}{[NO]^2[O_2]} = 6.6 \times 10^5$

For the new equation $NO_2(g) \rightleftharpoons NO(g) + \frac{1}{2}O_2(g)$,

the equilibrium constant = $K_2 = \dfrac{[NO][O_2]^{1/2}}{[NO_2]} = \dfrac{1}{\sqrt{K_1}} = \dfrac{1}{\sqrt{6.6 \times 10^5}}$

Question 4 **ANS C**

From the Data Book, hydrogen peroxide as an oxidant has an E^0 value of +1.77 V. As a reductant, hydrogen peroxide has an E^0 value of +0.68 V. Hence, hydrogen peroxide will react with itself spontaneously. It is important to note that the E^0 values give no information about the rate of reaction.

Question 5 **ANS D**

MnO_2 is a catalyst for the reaction and lowers the activation energy. Hence, more hydrogen peroxide molecules have sufficient energy to react.

Question 6 ANS A
When chemical bonds are broken, energy is absorbed. When chemical bonds form, energy is released. There is a net release of energy (exothermic reaction) because the energy absorbed in breaking all of the chemical bonds within the hydrogen and oxygen molecules is less than the energy released when the chemical bonds form to produce the water molecules.

Question 7 ANS A
Notice that the ΔH_c values given in the Data Book are for one mol of each substance.

Energy released (H_2) = $\frac{1.00}{2} \times 286 = 143$ kJ This is the largest.

Energy released (C) = $\frac{1.00}{12} \times 394 = 32.8$ kJ

Energy released (CH_4) = $\frac{1.00}{16} \times 889 = 55.6$ kJ

Energy released (C_2H_6) = $\frac{1.00}{30} \times 1557 = 51.9$ kJ

Question 8 ANS A
The forward reaction is endothermic. Therefore, the reverse reaction is exothermic. A decrease in temperature will favour the exothermic reaction. (Le Chatelier's Principle). The equilibrium position will shift to the left and the value of the equilibrium constant will decrease. There is an equal number of mole of gas on both sides of the equation. Hence, a change in volume does not change the position of equilibrium. An inert gas does not change the position of equilibrium. A catalyst does not change the position of equilibrium.

Question 9 ANS B
This is an exothermic reaction in which the heat content of the products is less than the heat content of the reactants. Energy is released. **Y** is the activation energy for the forward reaction. **Z** is the activation energy for the reverse reaction. **Y** the energy required to break the bonds in the reactants. **Z** the energy required to break the bonds in the products. **X** is the ΔH value for the reaction.
ΔH = H(products - H(reactants). This has a negative value.

Question 10 ANS B
To get the second equation from the first one, reverse the first equation and divide through by 2.

The new K_c value becomes $\sqrt{\dfrac{1}{0.010}} = 10$. The new unit becomes $\dfrac{M^1}{M^{\frac{1}{2}}} = M^{\frac{1}{2}}$.

The answer is 10 $\mathrm{M}^{\frac{1}{2}}$.

Question 11 ANS C
To get the second equation from the first one, reverse the first equation and divide through by 2.

The new ΔH value becomes $+\dfrac{58}{2}$. The unit remain the same; kJ mol^{-1}. ΔH for an equation is **always written** as kJ mol^{-1} , where mol^{-1} means "per mole of equation as written".
Answer is +29 kJ mol^{-1}.

Question 12 ANS D
To this equilibrium system, extra product in the form of H_3O^+(aq) is added. According to Le Chatelier's Principle, this will shift the equilibrium to the left. When equilibrium is re-established, there will be more HNO_2, more H_3O^+ and less NO_2^-. However, the concentration fraction $\dfrac{[H_3O^+][NO_2^-]}{[HNO_2]}$ will not have changed since the temperature remains constant.

Question 13 ANS D
Sodium metal reacts with water and even more violently with acids. It must be kept out of contact with water and acids. An inert gas like nitrogen or an inert organic liquid like kerosene is ideal.

Question 14 ANS B
See the Data Book Section 13.
The equation for the molar heat of combustion of octane is

$$C_8H_{18}(l) + \tfrac{25}{2}O_2(g) \rightarrow 8CO_2(g) + 9H_2O(g)\ ; \quad \Delta H = -5464 \text{ kJ mol}^{-1}$$

The energy released is 5464 kJ per mole of octane.

n(octane) = $\dfrac{228}{114} = 2$. Hence, the energy released = 2 × 5464 = 10 928 kJ.

Question 15 ANS B

$$\Delta H = \frac{k \times \Delta T}{1000 \times n}$$

$$\Delta T = \frac{\Delta H \times n}{k} = \frac{24.75 \times 1000 \times 0.100}{900} = 2.75 \text{ K}$$

Since ΔH is positive, the temperature change is negative.

Question 16 ANS D

The number of mole of electrons required to deposit all of the copper

$= 2 \times n(Cu^{2+})$

$= 2 \times \frac{1.876}{(63.6 + (2 \times 62.0))} = 2 \times \frac{1.876}{187.6} = 2 \times 0.01 = 0.02$

The number of mole of electrons required to deposit all of the silver

$= n(Ag^{+})$

$= 1 \times \frac{0.8495}{(107.9 + 14.0 + 48.0)} = \frac{0.8495}{169.9} = 0.005$

Hence, the quantity of electricity required = (0.02 + 0.005) × 96 500 = 2412.5 = 2413 C

Question 17 ANS C

In a galvanic cell, the positive electrode is the one to which the electrons flow, that is, the one at which the electrons are accepted. In this reaction, the oxidation number of silver changes from +1 to 0. Hence, Ag in $Ag_2O(s)$ has accepted an electron. $Ag_2O(s)$ is the positive electrode and has been reduced. It is the cathode because reduction **always** occurs at the cathode.

Question 18 ANS A

$Q = I \times t = 0.05 \times 10^{-3} \times 100 \times 24 \times 3600 \text{ C}$

$n(Ag_2O) = \frac{1}{2} \times n(e^-) = \frac{0.05 \times 10^{-3} \times 100 \times 24 \times 3600}{2 \times 96500}$

$m(Ag_2O) = \frac{0.05 \times 10^{-3} \times 100 \times 24 \times 3600}{2 \times 96500} \times ((107.9 \times 2) + 16)$

$m(Ag_2O) = \frac{0.05 \times 10^{-3} \times 100 \times 24 \times 3600}{2 \times 96500} \times 231.8$

$m(Ag_2O) = \frac{0.05 \times 10^{-3} \times 100 \times 24 \times 3600}{2 \times 96500} \times 231.8 = 0.52 \text{ g}$

Question 19 ANS A

Zn reduces Ag_2O to Ag. Hence, the E^0 of the $Zn(OH)_2(s)/Zn(s)$ electrode must be less than that of the $Ag_2O(s)/Ag(s)$ electrode.

Hence, E^0 ($Zn(OH)_2(s)/Zn(s)$) = -1.50 + 0.34 = -1.16 V

Question 20 ANS D

From (1) $E^0(Y) > E^0(X)$;

From (2) $E^0(Z) > E^0(X)$;

From (3) $E^0(Y) > E^0(Z)$

Hence, $E^0(Y) > E^0(Z) > E^0(X)$

End of Section A
Suggested Answers

Distribution: A 6 ; B 5 ; C 4 ; D 5

Question 1

Stage	**Equation**	***ΔH* value (+ or -)**
Energy produced by the sun	$4\ {}_1H^1 \rightarrow {}_2He^4 + 2e^+$ protons α-particle positrons	• Negative • Exothermic • Energy released
Energy stored in plants	$6CO_2(g) + 6H_2O(l) \rightarrow C_6H_{12}O_6(aq) + 6O_2(g)$	• Positive • Endothermic • Energy stored
Combustion of the coal in the power station furnace	$C(s) + O_2(g) \rightarrow CO_2(g)$	• Negative • Exothermic • Energy released
Oxidation of sulfur impurities in the coal	$S(s) + O_2(g) \rightarrow SO_2(g)$	• Negative • Exothermic • Energy released
Boiling water to provide steam to drive the generator	$H_2O(l) \rightarrow H_2O(g)$	• Positive • Endothermic • Energy stored

Question 2

a. **i.** $HCl(aq) + NaOH(aq) \rightarrow NaCl(aq) + H_2O(l)$

ii. $H_3O^+(aq) + OH^-(aq) \rightarrow 2H_2O(l)$ or $H^+(aq) + OH^-(aq) \rightarrow H_2O(l)$

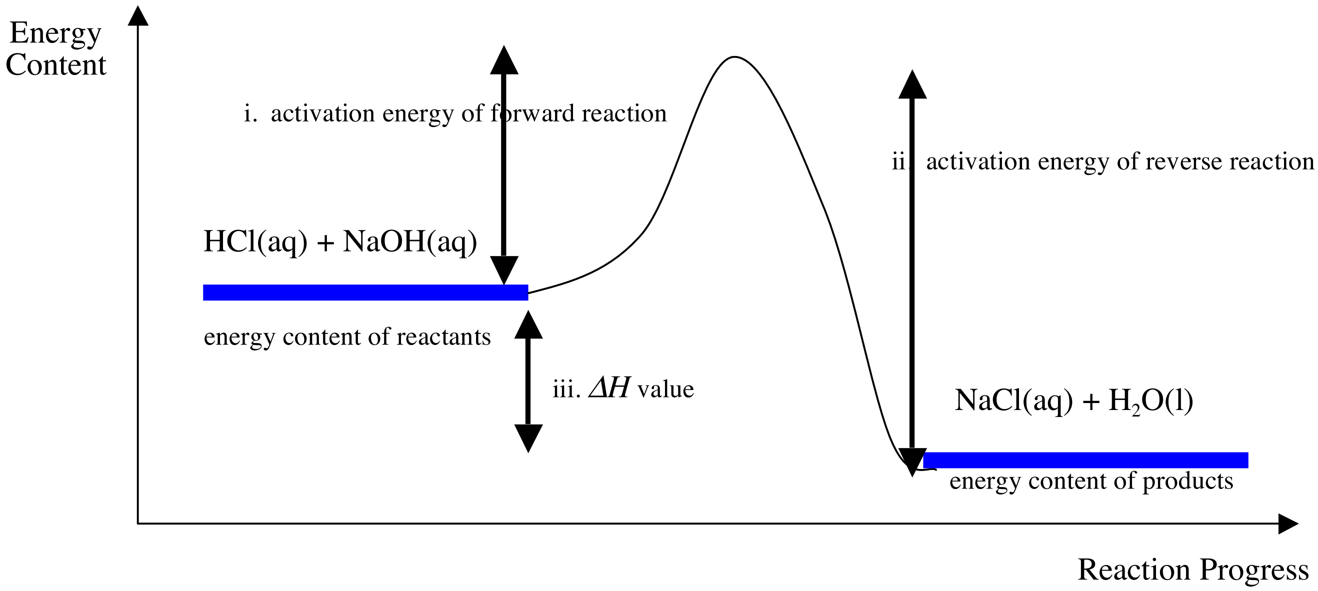
b. $n(HCl)$ reacting = $n(NaOH)$ reacting = $0.5 \times 0.1 = 0.05$ mol.

Energy released = 140×20.0 J.

Hence, $\Delta H = -\dfrac{140 \times 20.0}{0.05 \times 1000} = -56 \text{ kJ mol}^{-1}$

Question 2 (continued)

c. The energy profile is shown below.



d. **i.** The initial temperature of the calorimeter and its contents is 298 K. At this temperature, the value of K_w is 1.0×10^{-14}. After the reaction, the temperature rises to 318 K. The forward reaction is exothermic. Therefore, according to Le Chatelier's Principle, the reverse reaction is favoured and the $[H^+]$ and $[OH^-]$ both increase. Hence, the pH decreases. The pH is less than 7.

ii. The solution is neutral because $[H^+] = [OH^-]$. This is the definition of neutrality. The concentrations have increased by the same amount.

Question 3

a. $C_2H_5OH(aq) + 3O_2(g) \rightarrow 2CO_2(g) + 3H_2O(l)$

b. Mass(ethanol) = $\frac{2.9}{100} \times 500$

n(ethanol) = $\frac{2.9}{100} \times \frac{500}{46}$

Energy produced = $\frac{2.9}{100} \times \frac{500}{46} \times 1364(\text{Data Book}) = 430\ \text{kJ}$

Question 4

a. $CH_3CHOHCOOH(aq) + H_2O(l) \rightleftharpoons H_3O^+(aq) + CH_3CHOHCOO^-(aq)$

or $HC_3H_5O_3(aq) + H_2O(l) \rightleftharpoons H_3O^+(aq) + C_3H_5O_3^-(aq)$

b. Use the Data Book for the K_a value of lactic acid Assuming that the concentrations of $H_3O^+(aq)$ and $C_3H_5O_3^-(aq)$ are equal and that the concentration of $HC_3H_5O_3(aq)$ is very close to 0.001 M,

$$K_a(HC_3H_5O_3) = \frac{[H_3O^+]_e[C_3H_5O_3^-]_e}{[HC_3H_5O_3]_e} = \frac{[H_3O^+]^2}{[HC_3H_5O_3]} = 1.4 \times 10^{-4}\ \text{(Data Book)}$$

$$\Rightarrow [H_3O^+]^2 = 0.001 \times 1.4 \times 10^{-4} = 1.4 \times 10^{-7}$$

$$\Rightarrow [H_3O^+] = 3.74 \times 10^{-4}\ \text{M}$$

$$\Rightarrow \text{pH} = 3.43$$

c. When sodium lactate ($C_3H_5O_3Na$) is added to the equilibrium, $C_3H_5O_3^-(aq)$ ions are added. In accordance with Le Chatelier's Principle, this shifts the equilibrium position to the left. The hydronium ion (H_3O^+) concentration decreases and, therefore, the pH increases.

Question 5

a. $$K_c = \frac{[CH_3OH]}{[CO].[H_2]^2} = \frac{4.00}{0.10 \times (0.20)^2} = \frac{4.00}{0.004} = 1000\ \text{M}^{-2}$$

b. $[CH_3OH] = 1000 \times [CO] \times [H_2]^2$

K_c does not change since the temperature remains the same.

$[CH_3OH] = 1000 \times 0.2 \times 0.04$
$= 8.0$ M

c. The mixture of Cu, ZnO, and Al_2O_3 acts as a catalyst. It increases the rate at which equilibrium is reached by lowering the activation energy of the reaction. A catalyst provides an alternative pathway for the reaction.

Question 5 (continued)

d. 7 MPa is a very high pressure. More methanol is produced. Increasing the pressure in the reaction vessel shifts the equilibrium to the right since the reaction involves a **decrease** in the number of mole of gas (3 to 1).

e. 250°C is a **compromise temperature** because a low temperature favours the production of methanol since the reaction for the production of methanol is exothermic. However, care would need to be taken that too low a temperature did not slow the rate of reaction by too much. A catalyst enables a much lower temperature to be used than would normally be the case. 250°C is a compromise between yield of methanol and the rate at which equilibrium is reached.

Question 6

a.

Chemical	Equilibrium Reaction	Exothermic or endothermic
Ammonia	$N_2(g) + 3H_2(g) \rightleftharpoons 2NH_3(g)$	Exothermic
Ethene	$C_2H_6(g) \rightleftharpoons C_2H_4(g) + H_2(g)$ (many possible answers)	Endothermic
Nitric acid	$2NO(g) + O_2(g) \rightleftharpoons 2NO_2(g)$ *or* $4NH_3(g) + 5O_2(g) \rightleftharpoons 4NO(g) + 6H_2O(g)$	Both exothermic
Sulfuric acid	$2SO_2(g) + O_2(g) \rightleftharpoons 2SO_3(g)$	Exothermic

b.

Ammonia Reactants		Ammonia Product	
Element	Oxidation number	Element	Oxidation number
N	0	N	-3
H	0	H	+1

Ethene Reactant		Ethene Products	
Element	Oxidation number	Element	Oxidation number
C	-3	C	-2
H	+1	H	+1
		H	0

Question 6

b. (continued)

Nitric Acid Reactants		Nitric Acid Product	
Element	Oxidation number	Element	Oxidation number
N	+2	N	+4
O	-2	O	-2
O	0		

Sulfuric Acid Reactants		Sulfuric Acid Product	
Element	Oxidation number	Element	Oxidation number
S	+4	S	+6
O	-2	O	-2
O	0		

c. Many possible correct answers to these three questions

i. NH_3 (fertiliser), C_2H_4 (polymer manufacture),
HNO_3 (explosive manufacture), H_2SO_4 (dehydrating agent)

ii. ammonia forms $(NH_4)_2SO_4$, ethene forms $(C_2H_4)_n$,
nitric acid form NH_4NO_3, sulfuric acid forms $Ca(H_2PO_4)_2 + 2CaSO_4$

iii. NH_3 (carbon dioxide in the production of hydrogen), C_2H_4 (all hydrocarbons),
HNO_3 (nitrogen dioxide producing photochemical smog), H_2SO_4 (sulfur dioxide is a health hazard)

Question 7

a. At the cathode (-), an orange coating will form on the carbon electrode as copper metal is deposited in the reduction reaction: $Cu^{2+}(aq) + 2e^- \rightarrow Cu(s)$

At the anode (+) bubbles of a gas are formed. This is a pale yellow-green gas that has a distinctive strong smell. It is chlorine gas formed in the oxidation reaction:
$2Cl^-(aq) \rightarrow Cl_2(g) + 2e^-$. Note that the concentration of the chloride ion in the solution is 4.0 M (not the standard 1.0 M) and so the chloride ion will be oxidised in preference to water.

b. At the cathode (-), copper metal will be deposited until the concentration of copper ions in the solution becomes very low. At some point hydrogen gas will be produced in the reduction reaction: $2H_2O(l) + 2e^- \rightarrow H_2(g) + 2OH^-(aq)$. An appropriate indicator will show the presence of hydroxide ions around the anode. Note that magnesium metal will **not** be produced at the cathode because water is present.

At the anode (+), chlorine gas will be formed until the concentration of the chloride ion in the solution decreases. At some point another gas will be produced. This gas will relight a glowing splint. It is oxygen gas formed in the oxidation reaction:
$2H_2O(l) \rightarrow O_2(g) + 4H^+(aq) + 4e^-$. An appropriate indicator will show the presence of hydrogen ions around the anode.

Question 8

a. A galvanic cell produces its own polarity with spontaneous chemical reactions. Hence, in an oxidation reaction (anode) in a galvanic cell, the electrode is negative. For example, $Zn(s) \rightarrow Zn^{2+}(aq) + 2e^-$. On the other hand, an electrolytic cell has polarity forced upon it by an external power source. The negative terminal of the power source supplies electrons to the electrode. A non-spontaneous reaction occurs at the electrode. For example, the reduction reaction (cathode) in the electrolysis of water is
$2H_2O(l) + 2e^- \rightarrow H_2(g) + 2OH^-(aq)$

b. The balanced equation is: $Al^{3+}(l) + 3e^- \rightarrow Al(l)$.

Therefore, $n(e^-) = 3 \times n(Al) = 3 \times \frac{1500}{27.0}$

Now, $Q = I \times t = n(e-) \times F$.

Hence, $I = 3 \times \frac{1500}{27.0} \times \frac{96500}{3600} = 4467.6 = 4468$ A

c. Let Y = the number of electrons used in the reduction half-equation. In $Fe^{3+}(aq)$, the oxidation state of Fe is +3. The number of mole of $Fe^{3+}(aq) = \frac{1}{55.9}$

$n(e^-) = Y \times \frac{1}{55.9}$ and $n(e^-) = \frac{Q}{F} = \frac{5179}{96500}$

Hence, $Y = \frac{5179 \times 55.9}{96500} = 3$

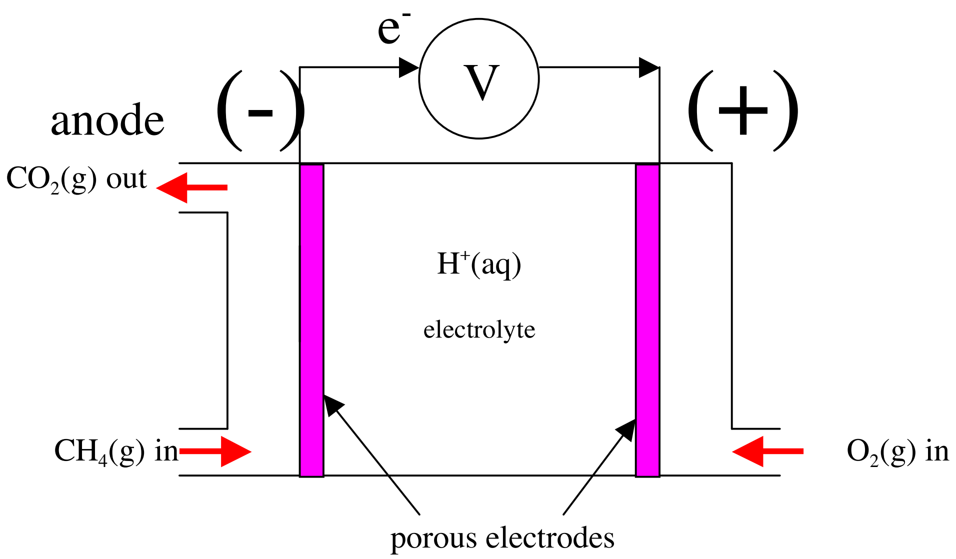
Therefore, the final oxidation number of iron = 3 - 3 = 0

The reaction occurring is $Fe^{3+}(aq) + 3e^- \rightarrow Fe(s)$

Question 9

a. **i.** The anode is the electrode at which oxidation (loss of electrons) occurs. It is negative. This is the electrode on the left hand side as shown below.

ii. The electrons flow from left to right through the external circuit (the voltmeter V) as shown below.



b. Anode half-reaction: $CH_4(g) + 2H_2O(l) \rightarrow CO_2(g) + 8H^+(aq) + 8e^-$

c. Cathode half-reaction: $O_2(g) + 4H^+(aq) + 4e^- \rightarrow 2H_2O(l)$

The overall cell reaction is obtained by adding the anode half equation to twice the cathode half equation as shown below.

$$CH_4(g) + \cancel{2H_2O(l)} \rightarrow CO_2(g) + \cancel{8H^+(aq)} + \cancel{8e^-}$$

$$2O_2(g) + \cancel{8H^+(aq)} + \cancel{8e^-} \rightarrow \cancel{4H_2O(l)}$$

$$CH_4(g) + 2O_2(g) \rightarrow CO_2(g) + 2H_2O(l)$$

Question 9 (continued)

d.

$CH_4(g) + 2H_2O(l) \rightarrow CO_2(g) + 8H^+(aq) + 8e^-$

From the half equation, assuming 100% efficiency, $n(CH_4)$

$$= \frac{1}{8} \times n(e^-)$$
$$= \frac{1}{8} \times \frac{Q}{F}$$
$$= \frac{1}{8} \times \frac{I \times t}{F}$$
$$= \frac{1}{8} \times \frac{10.0 \times 24 \times 3600}{96500}$$
$$= 1.1192$$

Hence, $V(CH_4)$ under SLC = 1.1192×24.5 dm^3 = 27.42 dm^3.

Since the process is only 75% efficient, the volume of CH_4 required will be **greater**.

$V(CH_4)$ required $= \frac{27.42}{0.75} = 36.6$ dm^3

END OF SUGGESTED SOLUTIONS

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