VCE CHEMISTRY
CAT 1 1992

"CHEMISTRY IN A PRACTICAL CONTEXT"

DETAILED SUGGESTED SOLUTIONS

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Section A

Question 1

Item 1 ANS B
The first step is to neutralise the acid. Solid sodium hydroxide must not be used since it is itself highly corrosive. Sodium chloride will react with concentrated sulfuric acid to produce hydrogen chloride gas. Paper towelling will react with the sulfuric acid. Use sodium bicarbonate (a weak base). Only carbon dioxide gas will be produced and eventually the acid will be neutralised.

Item 2 ANS A
The hydrochloric acid is approximately one tenth the concentration of the sodium hydroxide and only 50 ml of the acid is available in the burette. The volume of acid required will be approximately ten times the volume of hydroxide. The most appropriate volume for the pipette would be 2.00 ml. All of the other volumes would require the burette to be refilled with HCl which would result in errors.

Item 3 ANS B
Sodium hydroxide absorbs carbon dioxide from the air according to the equation: $NaOH(aq) + CO_2(g) = Na_2CO_3(aq) + H_2O(l)$. As a result, the concentration of the sodium hydroxide in the dish decreases with time. The evaporation of the solution would result in an increase in the concentation. Sodium hyroxide does not react with either oxygen or polyethylene.

Item 4 ANS B
$K = \frac{[HI]^2}{[H_2][I_2]} = 49$. Therefore, $[I_2] = \left(\frac{7}{3}\right)^2 \times \frac{3}{49} = \frac{1}{3}$ **ANS**

Item 5 ANS B
Surface tension is caused by the attraction of the molecules in the liquid for each other across the surface of the liquid. Water molecules form hydrogen bonds with each other which is a stronger form of bonding than the dispersion forces which exist between non-polar hexane molecules. The reference to detergent is irrelevant.

Item 6 ANS D
The surface tension of liquid water will be reduced by molecules which have one end polar and the other end non-polar. That is, one end of the molecule will be hydrophilic (water-loving, generally made up of ions) and the other end hydrophobic (water-hating, generally consisting of a hydrocarbon chain). The molecules are arranged with the hydrophobic end sticking out of the surface of the water. Neither $LiNO_3$ nor H_2O_2 has a hydrophobic end.

Item 7 ANS D
Ethylene undergoes addition polymerisation in the presence of a catalyst to form polyethylene according to the equation: $nC_2H_4(g) = (C_2H_4)_n(s)$.

Item 8 ANS B
Ethylene undergoes addition reactions with chlorine and water to form dichloroethane and ethanol respectively according to the equations: $C_2H_4(g) + Cl_2(g) = C_2H_4Cl_2(g)$; $C_2H_4(g) + H2O(g) = C_2H_5OH(l)$.

Item 9 ANS D
Ethylene is a gas at room temperature and pressure. It will burn readily (flammable) in oxygen according to the equation: $C_2H_4(g) + 3O_2(g) = 2CO_2(g) + H_2O(g)$

Item 10 ANS A
The mass of oysters required = $500 \times \frac{15}{100} = 75.0$ g

Item 11 ANS C
The soft drink contains 0.5 mg in 250 ml. This is 2.0 mg in 1000 ml (1 litre). From the graph, the absorbance = 4.

Item 12 ANS B
Bread contains 1 mg in 10g. Therefore, mass (zinc) = $1 \times \frac{2}{10}$ = 0.2 mg in 100 ml. Hence, the concentration of zinc = 0.2 x 10 = 2.0 mg in 1000 ml (1 litre). From the graph, the absorbance = 4.

Item 13 ANS B
Since the forward reaction is endothermic, raising the temperature will increase the yield of products. Since the forward reaction produces a larger number of mole of gas, lowering the pressure will increase the yield of products.

Item 14 ANS C
The number of mole of HCl does not change in a dilution process.
Therefore, $C_1 \times V_1 = C_2 \times V_2$ $\quad \frac{10}{1000} \times 0.0010 = C_2 \times 1$

$C_2 = 0.00001 \text{ M} = 10^{-5}$ M

pH = 5

Item 15 ANS A
$[OH^-] = \frac{10^{-14}}{10^{-5}} = 10\text{-}9$ M

Item 16 ANS C
Limestone reacts with hydrochloric acid according to the equation:
$CaCO_3(s) + 2HCl(aq) = CaCl_2(aq) + H_2O(l) + CO_2(g)$
From the balanced equation:
n(HCl) used up = 2 x n($CaCO_3$) = $2 \times \frac{2.50}{100.1} = 0.05$
n(HCl) initially = 0.5 x 0.2 = 0.1
Therefore, n(HCl) remaining = 0.1 - 0.05 = 0.05
Hence, the concentration of HCl remaining = $\frac{0.05}{0.2} = 0.250$ M

Item 17 ANS C
n(CO_2) produced = n($CaCO_3$) used up = $\frac{2.50}{100.1} = 0.025$
Therefore, V(CO2) at STP = 0.025 x 22400 = 560 ml.

Section B

Question 2

(a) $2Li(s) + 2D_2O(l) = 2LiOD(aq) + D_2(g)$

(b) n(LiOD) = C x V = 1 x 1 = 1. Hence, n(Li) = 1 and m(Li) = 1 x 6.9 = 6.9 g **ANS**

(c) The lithium deuteroxide dissociates into ions according to the equation:

$$LiOD(aq) = Li^+(aq) + OD^-(aq)$$

Question 3

SULFURIC ACID

A flowchart for the production of sulfuric acid is

BURNERS → CONVERTER → ABSORBER

In the burner, sulfur is burned in air according to the equation: $S(s) + O_2(g) = SO_2(g)$
Before further oxidation, the sulfur dioxide must be dried and purified to prevent the poisoning of the catalyst used in the next stage of production.
In the converter, sulfur dioxide reacts further with air to produce sulfur trioxide according to the equilibrium equation: $SO_2(g) + \frac{1}{2} O_2(g) \Leftrightarrow SO_3(g)$. This reaction is exothermic and produces a smaller number of mole of gas. Equilibrium principles would suggest that a higher yield of sulfuric acid would be produced in a given time by:
(1) using a low temperature
(2) using high pressure
(3) using an excess of air.

However, in practice low temperatures are not used since this would increase the time required to reach equilibrium. A compromise temperature of approximately 450 ^oC and a catalyst are used. High pressures are not used since the yield at atmospheric pressure is high and the extra yield does not justify the use of expensive pressure equipment. A moderate excess of air is used but not so much as to dilute the mixture excessively or increase pumping costs.

In the absorber the sulfur trioxide reacts with concentrated sulfuric acid to produce oleum which is diluted with water to produce 98% sulfuric acid. The equations for the reactions are:
$SO_3(g) + H_2SO_4(l) = H_2S_2O_7(l)$ and $H_2S_2O_7(l) + H_2O(l) = 2H_2SO_4(l)$
Direct reaction of sulfur trioxide with water is not used since the reaction is highly exothermic and vaporises the sulfuric acid.

Question 3 (continued)

AMMONIA

A flowchart for the production of ammonia is

COMPRESSOR → REACTOR → CONDENSOR

Nitrogen is obtained from the air and hydrogen from a variety of sources such as the steam reforming of natural gas: $CH_4(g) + H_2O(g) = CO(g) + 3H_2(g)$ or the electrolysis of water: $2H_2O(l) + 2e^- = 2OH^-(aq) + H_2(g)$. The nitrogen and hydrogen are mixed in a ratio of one part nitrogen to three parts hydrogen, compressed and then passed into the reactor. The equilibrium reaction that occurs is $N_2(g) + 3H_2(g) \Leftrightarrow 2NH_3(g)$. This reaction is exothermic with $\Delta H = -91$ kJ mol^{-1}. According to Le Chatelier's Principle, the yield of ammonia will be increased by using high pressure and low temperature. The actual pressure used is about 250 atmospheres. Economic considerations prevent higher pressures being used. Temperature poses a dilemma! Although a low temperature will give a high equilibrium yield of ammonia, equilibrium is reached far too slowly (slow reaction rates) when the temperature is low. A compromise temperature between 400^{o}C and 500^{o}C is used. It is only with the help of a catalyst (usually porous iron) that temperatures this low can be used to give a yield of ammonia in the range 10-20% within an acceptable time. Before equilibrium is reached, the reaction mixture is cooled in the condensor to liquefy the ammonia while the remaining gases are recycled to the reactor to improve the yield.

NITRIC ACID

A flowchart for the production of nitric acid is

CATALYTIC CONVERTER → COOLING CHAMBER → ABSORPTION TOWER

In this process, there is a gradual oxidation of N from -3 in NH_3 to +2 in NO to +4 in NO_2 and +5 in HNO_3.

In the catalytic converter, ammonia reacts with oxygen, in the presence of platinum, according to the equation: $4NH_3(g) + 5O_2(g) \rightarrow 4NO(g) + 6H_2O(g)$. This reaction is exothermic.
The reaction of ammonia with oxygen tends to produce nitrogen gas rather than nitrogen monoxide gas under normal circumstances. However, by using a catalyst of a platinum-rhodium alloy, the production of NO is favoured. This is the main reason for the catalyst in this reaction. Temperatures around 900^{o}C are used and the time of contact between the incoming gases and the catalyst are strictly controlled. In the cooling chamber, the nitrogen monoxide is cooled to 30^{o}C and reacted with air according to the equilibrium equation: $2NO(g) + O_2(g) \Leftrightarrow 2NO_2(g)$. This reaction is exothermic and produces a smaller number of mole of gas. Nitrogen dioxide is rapidly formed.

Question 3 (continued)

Equilibrium principles would suggest low temperatures and high pressures to achieve the best equilibrium yield. This is an unusual reaction in that reaction rate increases with decreasing temperature. Thus there is no conflict (as there is with ammonia) between the conditions required for large equilibrium yield and those required for economic reaction rate. In the absorption tower, water is mixed with the nitrogen dioxide and the reaction that occurs is: $3NO_2(g) + H_2O(l) = 2HNO_3(aq) + NO(g)$. The nitrogen monoxide produced reacts easily with air to produce more nitrogen dioxide which then reacts with water as above. A 50% solution of nitric acid is produced. This concentration can be increased by distillation.

Question 4

An emulsion is a suspension of very small droplets of one liquid suspended in another liquid. Emulsions consist of two phases - a polar phase and a non-polar phase. If the non-polar phase is dispersed in the polar phase, it is called an oil/water emulsion. An example of this is Mayonnaise. Molecules in the egg yolk in the recipe for Mayonnaise act as emulsifying agents (emulsifiers). They do this by attaching their hydrophobic ends to the oil droplets, thereby making the surface of the oil drop hydrophilic. This prevents the oil from settling out.

If the polar phase is dispersed in the non-polar phase, it is called a water/oil emulsion. Butter is an example of this.

Question 5

(a) $K_1 = \frac{[Hb_4(O_2)_4]}{[Hb_4]\,[O_2]^4}$ and $K_2 = \frac{[Hb_4(CO)_4]}{[Hb_4]\,[CO]^4}$

(b) Since the yield of $Hb_4(CO)_4$ is larger than the yield of $Hb_4(O_2)_4$, the value of K_2 is larger than the value of K_1.

(c) Carbon monoxide poisoning occurs because CO takes the place of O_2 in the haemoglobin complex, thereby depriving the body cells of their supply of oxygen. The equilibrium equation is: $Hb_4(O_2)_4(aq) + 4CO(g) \Leftrightarrow Hb_4(CO)_4(aq) + 4O_2(g)$. To oppose the effect of this poisoning, oxygen should be given to the patient at increased pressure (concentration). This will cause the reverse reaction to occur.

Question 6

(a) m(AgBr) initially = 0.50 g

n(Ag) produced = n(AgBr) reacting = $\frac{35}{100} \times \frac{0.50}{(107.9 + 79.9)} = 0.35 \times \frac{0.5}{187.8}$

m(Ag) produced = $0.35 \times \frac{0.5}{187.8} \times 107.9 = 0.10$ g **ANS**

(b) $n(Na_2S_2O_3)$ required = 2 x n(AgBr) remaining = $2 \times \frac{65}{100} \times \frac{0.5}{187.8}$

= 0.00346

= 3.5×10^{-3} mole **ANS**

Question 6 (continued)

(c) $n(Na_2S_2O_3)$ final = $n(Na_2S_2O_3)$ original - $n(Na_2S_2O_3)$ required
= (0.1 x 0.2) - 0.00346
= 0.02 - 0.00346
= 0.0165
= 1.65×10^{-2}

final concentration of $Na_2S_2O_3 = \frac{1.65 \times 10^{-2}}{0.1}$ = 0.165 M

Hence, change in concentration = 0.200 - 0.165 = 0.035 M **ANS**

Question 7

(a) Copper ore contains only a small proportion of the mineral $CuFeS_2$. Before the mineral can be reduced, it must be obtained in a more concentrated form. A flotation agent (xanthate) is added to the finely crushed ore which is held in suspension in water. Air is blown through the water and bubbles are formed which are rich in the xanthate/copper mineral. This froth is removed from the surface of the liquid.
Next the concentrate is roasted to remove much of the sulfur and to convert the iron to iron(II) oxide. The roasting reaction occurs according the following equation:

$2CuFeS_2(s) + 4O_2(g) \rightarrow Cu_2S(l) + 2FeO(l) + 3SO_2(g)$

As well as these three products, other sulfides and oxides of copper and iron are also produced. For example, FeS, CuS, Cu_2S, CuO. Finally, after the removal of the iron(II) oxide with silica to form a slag, the copper-containing material is reduced to metallic copper in the following exothermic reaction:
$Cu_2S(l) + O_2(g) = 2Cu(l) + SO_2(g)$

(b) **Environmental and Safety Problems.** Sulfur dioxide that is produced in the copper smelter is directly harmful to plants and animals. Acid rain is a solution of acidic gases in the moisture in the air. These gases include carbon dioxide, sulfur dioxide, sulfur trioxide, oxides of nitrogen. Since copper smelters are a source of sulfur dioxide and sulfur trioxide, they contribute to the incidence of acid rain according to equations such as:

$$SO_2(g) + H_2O(l) \rightarrow HSO_3^-(aq) + H^+(aq).$$

Also the wastes from the flotation cells are difficult to dispose of and the exhaust gases from the smelter must be filtered to remove fine particles of metals and metal oxides.

Question 8

(a) Pig iron is produced in a blast furnace using iron ore, limestone, coke and air.
Coke is added to the blast furnace to produce carbon monoxide (which is the reducing agent for the iron oxide) according to the equation: $2C(s) + O_2(g) = 2CO(g)$. The combustion of the coke provides the heat to melt the iron. Also the coke carries out the physical function of keeping the contents of the furnace porous so that the gases can move freely. This CO reduces the iron(III) oxide to Fe according to the equation: $Fe_2O_3(s) + 3CO(g) \rightarrow 2Fe(l) + 3CO_2(g)$
The limestone, calcium carbonate, is added to the blast furnace to act as a flux. It decomposes to calcium oxide which then reacts with several of the impurities to form a slag which floats on the molten iron and is easily removed. For example:
$CaCO_3(s) = CaO(s) + CO_2(g)$ and $CaO(s) + SiO_2(s) = CaSiO_3(s)$

(b) **Environmental and Safety Problems.** The following aspects of iron production need careful control to prevent damage to the environment. (1) carbon monoxide is very poisonous; (2) it is dangerous to work close to molten iron; (3) the noise levels in the plant can be very high; (4) oxide particles in the exhaust gases need to be removed; (5) hydrocarbon gases from coke manufacture need to be controlled; (6) water used throughout the plant needs to be recycled and cleaned before release.

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