2007 HSC Examination Paper

Sample Answers

Section I Part A

1 A Uranium, petroleum and aluminium are mined resources and will eventually be used up. Ethanol can be produced by the fermentation of sugary crops which can be regrown.

2 D Cellulose is a condensation polymer formed when water molecules are removed, allowing glucose molecules to link together.

3 B Electrons are produced by the reactant being oxidised. The anode is the electrode where the oxidation takes place. Electrons flow through the external wire toward the cathode, where the other reactant accepts electrons. Ions complete the circuit by moving through the salt bridge.

4 C The carbon atoms are numbered from the end closest to the functional group and the "hept" refers to the seven carbon atoms in the longest chain.

5 D Magnesium and lead are furthest apart on the reduction potential table, meaning they have the greatest potential difference between them.

6 C Phenolphthalein is an acid/base indicator that is colourless at pHs lower than around 8.5 and pink at basic pHs above 10.0. NaOH is the only basic substance listed.

7 D Acid–base neutralisation is exothermic and therefore the reaction profile needs to show a drop in enthalpy from reactants to products.

8 C Acid X will ionise more than acid Y because it is a stronger acid. It will therefore produce a higher concentration of hydronium ions, and therefore a lower pH.

9 A Sodium citrate is the only basic substance listed. Citrate is the strong conjugate base of the weak acid, citric acid.

10 C For the final pH to be 2.0, the concentration of HCL must be 0.01 mol L^{-1}. The acid must therefore be diluted 10 times: the volume needs to go from 90 mL to 900 mL, so an additional 810 mL of water needs to be added.

11 B Mg^{2+} and Ca^{2+} are the two ions that precipitate soap, reducing its ability to lather, causing the water to be hard.

12 A Carbon dioxide may not be produced if oxygen is limiting and carbon may not be produced if oxygen is in excess. Water is always produced.

13 A When the pressure is decreased the system will shift to partially counteract this change. Therefore the system will shift in reverse to increase the pressure by converting 2 moles of gas into 4 moles. As the reverse reaction is endothermic, this shift will also absorb heat.

14 D AAS uses the wavelength of the spectral line that is unique to the element being tested for.

15 B The chlorine free radical speeds up the decomposition of ozone but is recycled and can therefore be regarded as a catalyst.

Section I Part B

16 (a) X is the troposphere.

Y is the stratosphere.

(b) In the troposphere, ozone is a toxic pollutant. It reacts with biological molecules in living things by oxidising them impairing normal metabolism.

In the stratosphere, ozone absorbs uv radiation from the Sun.

$$O_3(g) + \text{uv (200–300 nm)} \rightarrow O_2(g) + O(g)$$

This absorption of uv radiation is vital to the continuation of life on Earth as uv causes skin cancer and cataracts in humans and other animals and interferes with the ability of plankton to photosynthesise, among other effects.

17 (a) $2HCl(aq) + Na_2CO_3(s) \rightarrow CO_2(g) + H_2O(l) + 2NaCl(aq)$

(b)

Solution	*Identity*
1	Sodium carbonate
2	Hydrochloric acid
3	Lead nitrate
4	Barium nitrate

(c) One of the solutions contains lead ions. Heating this solution will vaporise the lead which could then be breathed in. Lead is a highly toxic heavy metal.

18 The Maritime Museum employs analytical chemists to restore marine artefacts. An analytical chemist can identify the materials making up the artefact and then plan the best procedure to restore it. Wooden objects are submerged in water for long periods, so salts can leach out of the cells in the wood to help preserve it. The chemist uses a knowledge of *equilibrium* to monitor the concentration of the salts in the water. When the concentration ceases to rise, the salts are in equilibrium between the cells and surrounding water and the water can be replaced (if the salt concentration in the wood is still too high) or the artefact can be removed from the water.

19 The use of radioisotopes in industry and medicine has had a huge impact on society. In industry, they are used to gauge the thickness of materials such as steel, plastic and paper. The radiation emitted by an isotope passes through the material to a detector. Thicker materials absorb more radiation, so less passes through to a detector. Irregularities in thickness are detected and removed from the batch. Radioisotopes are also used to detect leaks in underground water pipes, avoiding the need to dig up long stretches of pipe to find the leak. Domestic smoke alarms use the radioisotope americium-241 in their operation. This isotope decays emitting alpha particles which ionise air molecules. The ionised particles complete an electric circuit which, when broken by large particles of soot, triggers an alarm. Americium-241 has a half-life of 432 years which is beneficial because it will never need replacing.

In medicine, radioisotopes are hugely beneficial, as they can be used to diagnose disorders without the need for invasive surgery. For example, iodine-131 is used to diagnose thyroid disorders. It is taken as a drink of sodium iodide which is selectively absorbed by the thyroid gland. The isotope emits gamma rays which can be detected outside the body by a gamma camera. High levels could indicate an overactive thyroid, low levels an underactive thyroid and abnormal levels thyroid cancer. This isotope can also be used to treat thyroid disorders as it is a beta emitter and beta rays destroy cells. It has a half-life of 8 days, so will not remain in the body for long. It is important that medical isotopes have short half-lives for this reason. Some radioisotopes can be used to irradiate and kill cancer cells, a huge benefit to society.

20 (a) Lead solid is the anode.

$$Pb(s) + PbO_2(s) + 2H_2SO_4(aq) \rightarrow 2PbSO_4(s) + 2H_2O(l)$$

(b) The benefit of lasting several years is that car batteries are not thrown away often. Because they contain lead, this reduces the amount of lead in the environment. Lead is a toxic heavy metal. It is absorbed by living things and concentrates as it passes up the food chain.

21 (a) $H_2SO_4 \rightarrow 2H^+ + SO_4^{2-}$

$[H^+] = 2 \times 0.005 \text{ mol L}^{-1}$

$= 0.01 \text{ mol L}^{-1}$

$pH = -\log[H^+]$

$= 2$

The indicator would be red.

(b) $pH = -\log[(0.005 \times 2) \times 0.1]$

$= 3$

The indicator would be violet.

(c) $2\,KOH + H_2SO_4 \rightarrow 2H_2O + K_2SO_4$

$n(H_2SO_4) = 0.0005 \times 0.015$

$= 7.5 \times 10^{-6}$

$n(KOH) \text{ needed} = 7.5 \times 10^{-6} \times 2$

$= 1.5 \times 10^{-5} \text{ mol}$

$V(KOH) \text{ needed} = \dfrac{1.5 \times 10^{-5}}{0.005}$

$= 3 \times 10^{-3} \text{ L}$

$= 3 \text{ mL}$

22 (a) 50 ppm = 50 g S per 1,000,000 g solution

In 60 kg of solution, (60,000 g) there would be 3 g S.

$$n(\text{S}) = \frac{3}{32.07}$$

$$= 0.0935 \text{ mol}$$

$S + O_2 \rightarrow SO_2$

$n(SO_2) = 0.0935$ mol

$V(SO_2) = 0.0935 \times 24.79$

$= 2.32$ L

(b) It is important to reduce the amount of sulfur in the atmosphere because sulfur reacts with oxygen forming sulfur dioxide.

$$S(s) + O_2(g) \rightarrow SO_2(g)$$

This is further oxidised to sulfur trioxide and this reacts with moisture in the atmosphere forming acid rain.

$$2SO_2(g) + O_2(g) \rightarrow 2SO_3(g)$$

$$SO_3(g) + H_2O(l) \rightarrow H_2SO_4(aq)$$

Acid rain affects both the urban and natural environments. In cities, acid rain dissolves limestone and marble statues and buildings. This destroys historically important structures that cannot be replaced.

$$CaCO_3(s) + H_2SO_4(aq) \rightarrow CO_2(g) + H_2O(l) + CaSO_4(aq)$$

In the natural environment, acid rain damages vegetation in forests and reduces the pH of rivers and lakes which has a detrimental effect on the organisms living in them.

Sulfur dioxide also has an irritating effect on respiratory systems and reduces the quality of life for people living in cities.

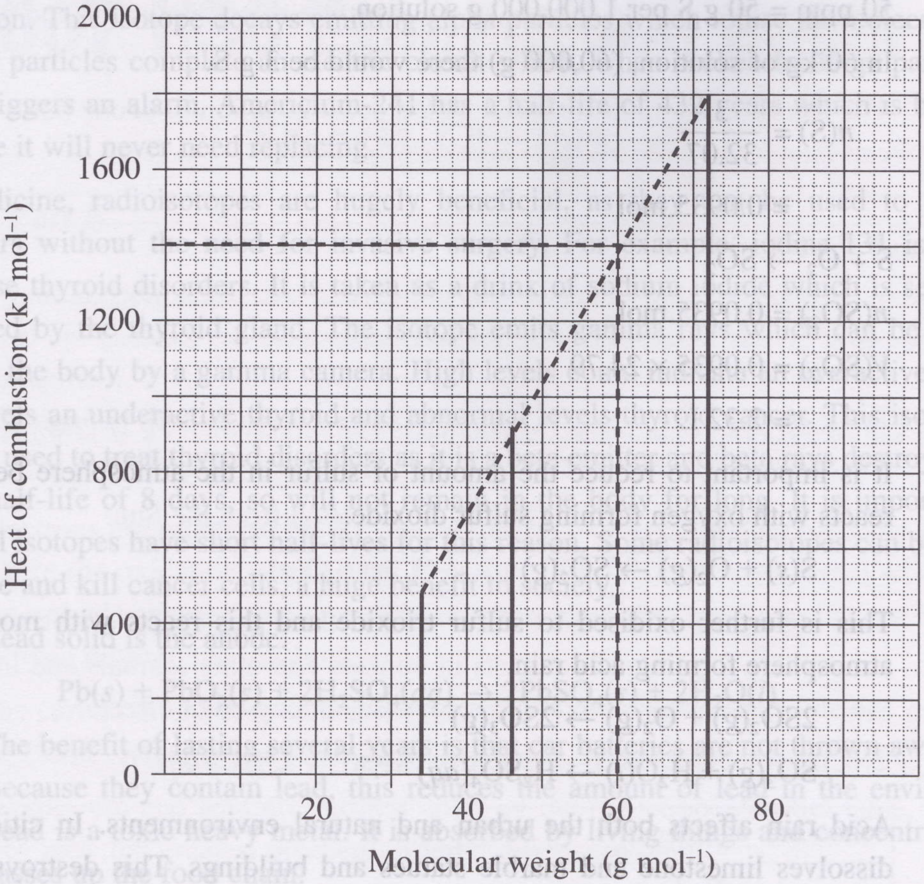
The sulfur reduction policy is valuable as it reduces the effects of all of these occurrences.

23 Pure hexanoic acid and ethanol are mixed with a few drops of concentrated sulfuric acid and heated for at least an hour under reflux (with an upright condenser attached to the reaction flask)

The products are water, H-O-H and ethylhexanoate,

$$CH_3CH_2CH_2CH_2CH_2CH_2COOCH_2CH_3$$

24 (a)



(b) (i) 1400 kJ mol^{-1}

(ii) The theoretical value assumes complete combustion. The estimated value would include some incomplete combustion because the fuel was burnt in air which only contains 20% oxygen.

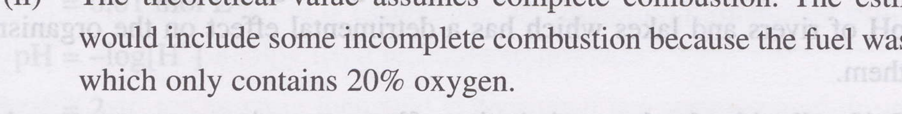
25 $NaHCO_3$ is a very effective agent in neutralising chemical spills for a number of reasons. It is an amphiprotic substance and as such will neutralise both acid and base spills.

$$HCO_3^- + H_3O^+ \rightarrow H_2CO_3 + H_2O$$

$$HCO_3^- + OH^- \rightarrow CO_3^{2-} + H_2O$$

When used to neutralise acids, it acts as a weak base so that the excess that remains after neutralisation is essentially harmless (it is used in food). It is a solid and as such is easy to control, spread and clean up afterwards. $NaHCO_3$ also has an advantage over other neutralising substances in that it reacts with acid forming a gas; thus, it is easy to tell when the reaction is complete as it stops fizzing.

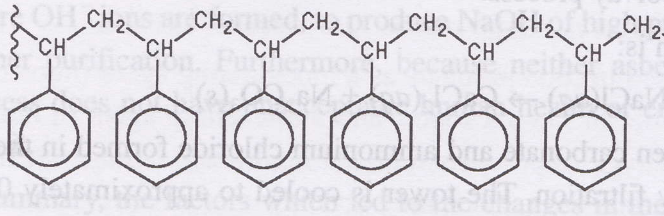
26 Polyethylene can be produced in two forms with different structures, high density polyethylene (HDPE) and low density polyethylene (LDPE). HDPE consists of very long chain carbon molecules without branches.



The chains can pack closely together forming a high-density, crystalline substance that is strong with a high melting point. This structure gives strength to the plastic and it is used to make garbage bins, tough plastic freezer bags and rigid toys.

LDPE also consists of long carbon chains but with significant alkyl branching. The molecules cannot pack so closely together and this results in a lower-density plastic that is softer and has a lower melting point, useful for making cling wrap, more flexible toys and plastic bottles. Both types of polyethylene are resistant to water and are nonbiodegradable, properties that are useful for their functions.

Polystyrene consists of a long carbon chain with a phenyl branch on every second carbon.



If gas is bubbled through the plastic as it is polymerising, a light-weight, spongy foam plastic forms. This structure gives a material that resists shock and is used to pack fragile devices when they are transported. The low mass is useful in that it does not add to shipping costs. It is water resistant and fairly strong. Polystyrene is also used to make surfboards owing to its low density and water resistance.

27 (a) When $AgNO_3$ is added to the sample, the silver ion precipitates the chloride to form solid silver chloride.

$$Ag^{+}(aq) + Cl^{-}(aq) \rightarrow AgCl(s)$$

The $AgNO_3$ is added until no more precipitate forms. All the chloride has then precipitated. The precipitate is collected in the filter and can be dried and weighed. From the mass, the moles of $AgNO_3$ can be calculated and from this, the moles of chloride. As long as the initial volume of the water sample is known, the concentration of chloride can then be calculated as concentration = moles/volume.

(b)
$$\% \text{ Cl}^{-} \text{ in AgCl} = \frac{35.45}{143.35} \times 100$$
$$= 24.73\%$$
$$m(\text{Cl}^{-}) \text{ in 3.65g AgCl} = 0.9026 \text{ g in 50 g } H_2O$$
$$\text{conc.} = \frac{1{,}000{,}000}{50} \times 0.9026$$
$$= 18{,}053 \text{ ppm}$$
$$= 1.81 \times 10^{4} \text{ ppm (3 sig.fig.)}$$

(c) The chloride ion concentration is a major component of the concentration of total dissolved solids (TDS). A low concentration of TDS improves the taste of water but over a certain concentration, the TDS gives water an unsatisfactory salty taste.

Options Topics
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Sample Answers

Question 28 Industrial Chemistry

(a) (i) The process is the Solvay process.

The overall equation is:

$$CaCO_3(s) + 2NaCl(aq) \rightarrow CaCl_2(aq) + Na_2CO_3(s)$$

(ii) The sodium hydrogen carbonate and ammonium chloride formed in the tower are simply separated by filtration. The tower is cooled to approximately 0°C, and at this temperature $NaHCO_3$ has a very low solubility whereas NH_4Cl is soluble. Thus the $NaHCO_3$ precipitates as it forms and is removed by filtration.

(b) All three processes use saturated, purified brine as the starting material, and produce chlorine gas, hydrogen gas and aqueous NaOH. Each of the processes produces chlorine gas at an inert anode by oxidation of chloride ions: $2Cl^- \rightarrow Cl_2 + 2e^-$.

In the mercury process for production of NaOH the cathode is flowing liquid mercury, and at this electrode sodium ions are reduced to sodium metal:

$$Na^+ + e^- \rightarrow Na.$$

The sodium dissolves in the mercury to produce an amalgam, which is sprayed into water in a separate compartment. The sodium reacts with the water to produce $NaOH(aq)$, and the mercury is recycled:

$$2Na(s) + 2H_2O(l) \rightarrow 2NaOH(aq) + H_2(g).$$

Although this process produces high-purity NaOH, it also has high energy requirements, and it is a two-stage process. Both of these factors are industrially undesirable and contributed to the development of the asbestos process. However, the most important factor which contributed to the change in production process is the unavoidable release of mercury into the environment by this process. Mercury is a bioaccumulating neurotoxin and thus is very dangerous in the environment. Avoiding mercury poisoning was a major factor in changing the production process. Also, mercury is expensive, so replacing the lost mercury was a significant cost.

The diaphragm process was developed next, and has the same anode reaction as the mercury process. However, water is reduced at a steel mesh cathode to produce hydroxide ions and hydrogen gas. The anode and cathode compartments are separated by an asbestos diaphragm which allows Na^+ ions to pass through, as they are attracted to the cathode, at which OH^- ions form. Thus a solution of $NaOH(aq)$ is formed.

There are two factors which contributed to the phasing out of this process in many countries. First, even though it has lower energy requirements than the mercury process, and is a single-stage process, some chloride ions cross the diaphragm, and thus the product is contaminated with NaCl. This is industrially undesirable because the NaOH must then be purified before it can be sold. This consumes time and resources. Furthermore, asbestos has been found to be a carcinogen, causing asbestosis in exposed workers. These two factors contributed to the change in production process to the membrane process.

In the membrane process, the anode and cathode reactions are the same as in the diaphragm process, but the anode and cathode compartments are separated by a special, selectively permeable polymer membrane. It allows Na^+ ions to cross, but not anions or water. Thus Na^+ ions can move from the anode compartment to the cathode compartment, where OH^- ions are formed, to produce NaOH of high purity, thus removing the need for further purification. Furthermore, because neither asbestos nor mercury are used, the process does not have unacceptable human health or environmental hazards associated with it.

In summary, the factors which led to the changes in the production processes in NaOH production were human health, environmental and product purity concerns, and costs. Addressing these has led chemical engineers from the mercury process, to the diaphragm process to the current best practice, the membrane process.

(c) (i) $K = \dfrac{[H_2O]^2}{[H_2S]^2[SO_2]}$

(ii)

	$[H_2S]$	$[SO_2]$	$[H_2O]$
initial concentrations	1.00	1.00	0
final concentrations	0.50	0.75	0.50

$$K = \frac{0.50^2}{0.75 \times 0.50^2} = 1.33$$

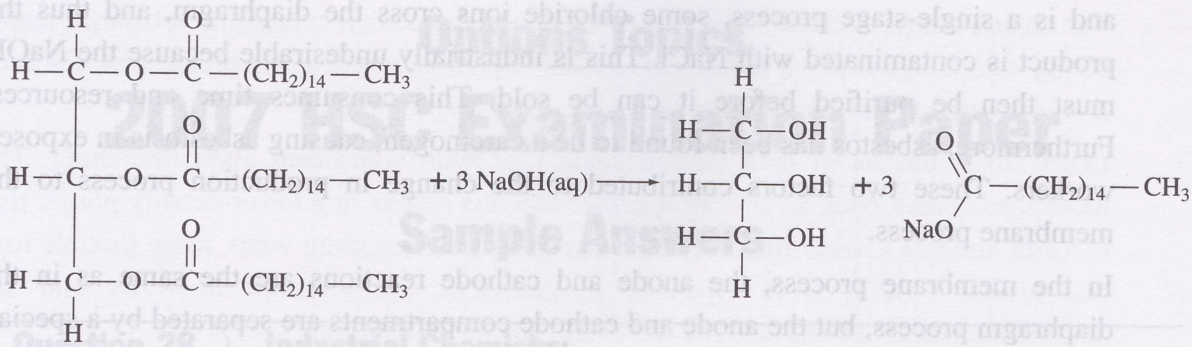
Note: the data is provided to 3 significant figures, and thus so is the answer.

(iii) Four factors which would maximise the removal of H_2S, and therefore the forward reactions are:

- using an excess of $SO_2(g)$
- Increasing the pressure of the system (because there are fewer moles of gas on the RHS)
- Cooling the system (because the forward reaction is exothermic)
- Removal of water vapour

Note: this question only asks you to 'identify' the factors.

(d) Saponification is the hydrolysis in alkaline conditions of a triglyceride, producing glycerol and the sodium salt of fatty acids. The sodium salts are used as soaps. For example:



The products of saponification, glycerol and soaps, have had an enormous impact on society and the environment.

- Glycerol has been used in food products as a moisturising agent (humectant), as a sugar substitute, a filler in low-fat foods, and a thickening agent in liqueurs. It is also used in personal hygiene products such as mouthwash, toothpaste, and shaving creams, to provide smoothness, lubrication and moisture retention. Thus it has had a huge impact on society, by improving the quality of foods and personal hygiene products available.
- Soaps have also had a huge impact on society and the environment. By allowing improved personal hygiene and sanitation, soaps have contributed to our improved health and the reduction in disease.
- Because soaps precipitate as Mg^{2+} and Ca^{2+} salts in hard water, they led to the development of synthetic anionic detergents. These were initially highly branched structures, which were not biodegradable. Thus their disposal generated huge amounts of soap froth in natural waterways, which was a very negative environmental impact. The nonbiodegradable soap froth clogged up natural ecosystems, prevented light penetration, and disrupted aquatic ecosystems. However, the subsequent development of straight-chain anionic detergents had positive environmental impacts because they are biodegradable, thus alleviating these problems.

(e) (i) The class was divided in two, with each half standing on opposite sides of the room. One group was given ten balls, the other group two. Each person holding a ball threw it across the room during a time period. Throwing was then stopped and the number of balls on each side was counted. The process was repeated a number of times. The results we obtained were that after a small number of throws the number of balls on each side became constant, and the two numbers were the same. To model the effect of changing concentration we added more balls to one side. The result of this was that eventually the number of balls on each side became constant again.

(ii) One risk associated with this procedure is that someone could be hit with one of the balls, or that one of the balls could hit and break a glass object.

(iii) This procedure modelled equilibrium because:

- it was a closed system: the total number of balls did not change;
- eventually it shows equal forward and reverse reaction rates: the number of balls going in each direction is the same;
- it shows constant microscopic change: balls move from one side to the other with each throw;
- it shows constant macroscopic properties: the number of balls on each side becomes constant;
- it models the effect of changing concentration: by adding more balls to one side the reaction rate in one direction increases but eventually forward and reverse rates become equal again and the number of balls on each side becomes constant again.

The model had limitations because it did not adequately reflect the reality of equilibrium systems. For example, our procedure did not show reactants becoming products – i.e. it did not allow us to visualise a chemical reaction. Nor did it give any information about reaction mechanisms.