Core Topic 3

Chemical Monitoring and Management

Worked Answers

Multiple-Choice Answers

1 A AAS is used to determine the concentration of metal ions in a substance. To do this, the metal ions are nebulised into a flame and the absorption spectrum recorded and analysed.

2 B The presence of sulfate is determined by the addition of $BaCl_2$ solution to a solution of the unknown substance; a white precipitate is evidence of the presence of sulfate. All nitrates are soluble and will not form precipitates.

3 C The longest carbon chain in the molecule is 5 carbons and there are no double or triple carbon bonds, so the molecule is a pentane derivative. The substituents are a methyl group, two chlorines and a fluorine. This gives prefixes (in alphabetical order) of: dichloro, fluoro and methyl. The carbons to which these substituents are bonded are numbered to give the lowest series of numbers and the resulting name is: 1,2-dichloro-2-fluoro-3-methylpentane.

4 D Ethylene is used to produce ethanol industrially.

5 C The presence of a catalyst in a reaction lowers the activation energy of the reaction, allowing equilibrium to be reached more quickly. The presence of a catalyst in an equilibrium reaction will not change the amounts of products or reactants at equilibrium.

6 A The reaction is exothermic. When temperature is increased the reverse reaction, being endothermic, is favoured to absorb the heat and therefore reduce the yield of ammonia, the product.

7 C The Haber process is an exothermic equilibrium process to convert nitrogen and hydrogen gases to ammonia gas. The double arrows show that the process is an equilibrium system and the negative sign on the ΔH value shows that it is exothermic.

8 B Ozone is toxic to humans in the lower atmosphere but protects the Earth from harmful UV rays in the upper atmosphere; carbon monoxide is a poison that replaces oxygen in the blood. Nitrogen and argon are inert gases.

9 D CFCs contain only carbon, chlorine and fluorine. If hydrogen is present the gas is not a CFC.

10 B The majority of the ozone in the atmosphere is found in the stratosphere.

11 C Solution X has two pieces of data that lead to the conclusion that the cation is barium: a precipitate forms when sulfate is added and a green flame. Solution Y contains lead, as it has the characteristic yellow precipitate when iodide is added. Solution Z contains copper as a (gelatinous) precipitate formed when hydroxide was added and a blue-green flame was noted.

12 C AAS (atomic absorption spectroscopy) is used for the determination of metal ion concentrations. Metal ions are cations and AAS is sufficiently sensitive to determine trace concentrations of these cations.

13 C W contains H, Cl and F and is a HCFC; X contains only C and H and is a hydrocarbon; Y contains Cl and F and is a CFC; Z contains Cl, Br and F and is a halon.

14 D Functional groups are named in alphabetical order, disregarding the prefixes denoting the number of each type.

15 C Exothermic reactions produce heat, therefore decreasing the temperature removes one product and will cause the reaction to proceed to the product side by Le Chatelier's principle. In this system, there are 4 moles of gas on the reactant side and only 2 moles on the product side, therefore increasing the pressure will cause a movement to the product side of the reaction according to Le Chatelier's principle.

16 C Allotropes are different physical forms of the same element, with different physical properties but identical chemical properties.

17 D Vehicle exhausts have never been a source of CFC pollution. Vehicles emit other types of pollution such as oxides of nitrogen and carbon monoxide.

18 B $O_3 + Cl \rightarrow O_2 + OCl$

19 C The numbering of the carbon atoms in a hydrocarbon must give the lowest series of numbers, in this instance that is 2,3. The chlorine is on carbon 2 and the bromine on carbon 3. The functional groups are named in alphabetical order and the name of the molecule is: 3-bromo-2-chlorohexane.

20 D Flame tests determine the presence of cations not anions. Of the options, only two are cations: Pt and Ba. Platinum does not change the colour of the flame from yellow but barium gives a green flame.

21 A Water is termed 'hard' when magnesium and calcium are present.

22 B Only solvent flows through a membrane and it does so in a manner to equalise the pressure (concentration) on either side of the membrane. The solvent will flow from the dilute to the concentrated side of the membrane.

23 A Exothermic reactions have heat as a product, therefore decreasing the temperature removes one product and causes the reaction to proceed to the product side by Le Chatelier's principle. In this system, there are 4 moles of gas on the reactant side and only 2 on the product side, therefore increasing the pressure will cause a movement to the product side of the reaction according to Le Chatelier's principle.

24 B A catalyst increases the rate of an equilibrium reaction by decreasing the activation energy of both the forward and reverse reactions, but it does not change the equilibrium yield.

25 C In order to determine the presence of sulfate in a compound, barium ions are added in the form of $BaCl_2$ solution. The presence of a precipitate indicates that sulfate is present.

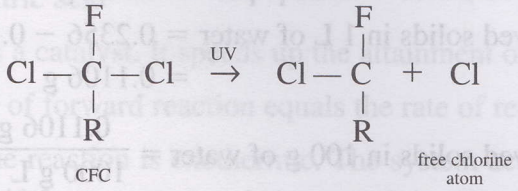
Free-Response Answers

26 (a) Chlorofluorocarbons

(b) Any one of the following, or similar places of origin. Note only one is necessary.

- Coolant in refrigerators, air conditioners, etc.
- Propellants in aerosol cans.
- Plastic foam, as it was used to make bubbles in plastics.
- Solvents.

(c) The CFC breaks down in UV light to form a free chlorine atom.



The free chlorine atom reacts with ozone to produce an oxygen molecule and chlorine monoxide

$$Cl + O_3 \rightarrow O_2 + ClO$$

Chlorine monoxide reacts with atomic oxygen to produce molecular oxygen and a chlorine atom , which is then able to repeat the above process.

$$O + ClO \rightarrow O_2 + Cl$$

(d) Ozone in the upper atmosphere, commonly known as the ozone layer, acts to absorb damaging UV radiation. CFCs have been shown to be responsible for producing holes or thinning of this layer, causing increased levels of UV radiation to reach the Earth. In the lower atmosphere, ozone acts as a greenhouse gas and is a component of photochemical smog. CFCs also destroy this ozone. In this way it helps to lower harmful effects of ozone in the lower atmosphere.

27 (a) If a system at equilibrium is disturbed, then the system adjusts itself so as to minimize the change.

(b) (i) Conditions of Haber process

- a pressure of about 35 MPa
- use of a catalyst — iron
- temperature of 400 to 500°C
- the ammonia is liquified to separate it
- unreacted gases are sent around again

(ii) A trade-off is met with the temperature, which is moderate, to allow for an increase in the reaction rate so that equilibrium is achieved more quickly. According to Le Chatelier's Principle, the above equilibrium would be forced to the production of ammonia, at low temperatures, as the reaction is exothermic.

OR similarly

A catalyst is added to allow equilibrium to be reached quickly. It does this by lowering the activation energy of the reaction. The reaction is more cost efficient as maximum yield is achieved in the shortest possible time.

28 (a) Wt of filter paper 5 0.1250 g

Wt of undissolved solids + filter paper = 0.2356 g

Wt of undissolved solids in 1 L of water = 0.2356 − 0.1250 g

= 0.1106 g

$$\text{Wt of undissolved solids in 100 g of water} = \frac{0.1106\text{ g}}{1000\text{ g L}^{-1}} \times 100\text{ g}$$

= 0.01106 g

% of undissolved solids = 0.01106%

Wt of basin = 32.126 g

Wt of basin + dissolved solids = 32.375 g

Wt of dissolved solids in 1 L of water = 32.375 g − 32.126 g

= 0.249 g

$$\text{Wt of dissolved solids in 100 g of water} = \frac{0.249\text{ g}}{1000\text{ g L}^{-1}} \times 100\text{ g}$$

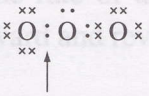
= 0.0249 g

% of undissolved solids = 0.0249%

(b) Biochemical oxygen demand (BOD). This indicates the amount of oxygen removed by organic matter in the water.

(c) Various types of pollution may occur. One possible answer is pollution by fertilisers due to runoff from local farms.

29 (a)



Coordinate covalent bond — both electrons come from the central oxygen atom

(b) In the coordinate covalent bond both electrons come from the central oxygen atom.

30 Octane complete combustion: $2C_8H_{18} + 25O_2 \rightarrow 16CO_2 + 18H_2O$

possible incomplete reaction: $2C_8H_{18} + 17O_2 \rightarrow 16CO + 18H_2O$

or $2C_8H_{18} + 13O_2 \rightarrow 8CO + 8C + 18H_2O$

Impurity of sulfur $S + O_2 \rightarrow SO_2$

or $2S + 3O_2 \rightarrow 2SO_3$

Nitrogen from air $N_2 + O_2 \rightarrow 2NO$

or $2NO + O_2 \rightarrow 2NO_2$

Monitoring of pollutants from these situations is necessary in cities especially because of health hazards from CO, NO_2 and SO_2.

31 (a) Reversible (reaction proceeds in both directions)

(b Fertiliser or nitric acid

(c) Iron is used as a catalyst. It speeds up the attainment of equilibrium.

(d) (i) The rate of forward reaction equals the rate of reverse reaction.

(ii) (I) The reaction is exothermic. The system acts to counteract the change, so if the temperature is increased then the reaction will proceed in the endothermic direction, ie towards the reactants, and hence less ammonia is produced.

(II) 4 mol of reactants produces 2 mol of products; therefore if the system acts to counteract the change of increased pressure, it would lead to more products to reduce the pressure, and hence more ammonia is produced.

(iii) 1000 atm is too expensive to maintain and at 1000°C reaction rate is too slow.

32 (a) Add Ba^{2+} ions and a white precipitate would form with SO_4^{2-} ions. No precipitate would form with Cl^- ions.

(b) If a solution of the ion is sprayed into a Bunsen flame and it gives a yellowy-green flame, the ion present is barium. If it gives a red flame, the ion present is calcium.

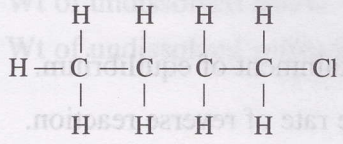
33 The layers of the atmosphere, starting from the Earth's surface, are the troposphere, the stratosphere and the mesosphere. The lowest layer, the troposphere is composed of a mixture of the main gases nitrogen and oxygen, as well as other gases released into the atmosphere at ground level such as carbon dioxide, oxides of nitrogen and carbon monoxide.

34

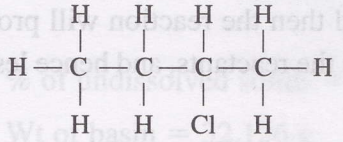
Major pollutant	*Major source*
Carbon monoxide	Motor cars; bush and forest fires, slow combustion stoves.
Oxides of nitrogen (NO and NO_2)	Combustion (vehicles and power stations)
Hydrocarbons	Vehicles, factories using solvents

35 Oxygen consists of a pair of oxygen atoms joined by a double bond whereas ozone consists of three oxygen atoms joined together. There is a double covalent bond between two of the oxygen atoms. One of the lone pairs of electrons on one of the oxygen atoms forms a new covalent bond with the third oxygen atom; this is a coordinate covalent bond.

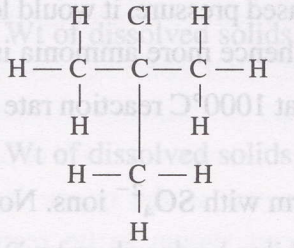
36 Any two of the following



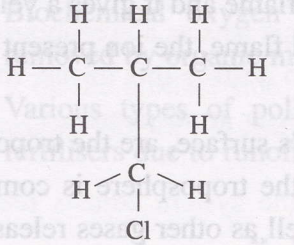
1-chlorobutane



2-chlorobutane



2-chloro-2-methylpropane



1-chloro-2-methylpropane

37 In atomic absorption spectroscopy each metal ion is measured separately because each metal ion requires a special lamp. The lamp contains the element being analysed and generates wavelengths of light specific to the metal ion being analysed. The solution to be examined is vaporised. The light beam is then passed through the vaporised sample. Some of the light is absorbed by the vaporised sample. By measuring the fraction of the light at a specified wavelength that is absorbed, we can determine the concentration of the element. Atomic absorption spectroscopy is extremely sensitive allowing concentrations of 0.01 ppm to be detected.

38 (a) $2C_8H_{18} + 25O_2 \rightarrow 16CO_2 + 18H_2O$ Complete

$2C_8H_{18} + 12\frac{1}{2}O_2 \rightarrow 7CO + 18H_2O + 9C$ Incomplete

(b) An insufficient amount of oxygen leads to incomplete combustion as shown above.

39 (a) Carbon monoxide

(b) NO_2 from car internal combustion engines.

O_3 from the reaction of O_2 with an O radical from the decomposition of NO_2.

40 (a) The reaction can proceed in either the forward or reverse directions. Reversible reactions are equilibrium reactions.

(b) The Haber process is the synthesis of ammonia reaction.

(c) $N_2(g) + 3H_2(g) \rightleftharpoons 2NH_3(g)$

(d) Reactants. Because the reaction is exothermic, the products plus the energy released is equal to the energy of the reactants.

41

Change	*Effect*	*Explanation*
Increasing pressure	Increase	According to Le Chatelier's Principle, when a system at equilibrium is disturbed then the system will de driven in the direction that will minimise the disturbance. In this case increasing pressure will drive the reaction towards less pressure, ie towards the products thus increasing the yield of ammonia.
Addition of catalyst	No change	The role of the catalyst is to allow the reaction to reach equilibrium in a shorter period of time.

42 (a) $3H_2(g) + N_2(g) \rightleftharpoons 2NH_3(g)$

(b) When a high temperature is used the reverse reaction would be favoured, reducing the yield of product, because the forward reaction is exothermic. However if a low temperature is used there would not be enough reaction energy for the reactants to react. A balance is adopted whereby a moderate temperature and catalyst are used so that reactants still react but the reverse reaction is only favoured slightly so as not to reduce the yield significantly.

43 Barium ion: A sample of the solution is sprayed into a Bunsen burner flame; apple green colour confirms the presence of barium.

Sulfate ion: Add, dropwise, a solution of barium nitrate. A very fine, white precipitate confirms the presence of sulfate. This precipitate will pass through filter paper.

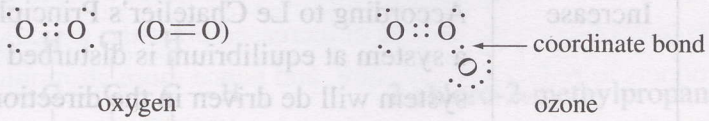
44 (a) Each metallic cation displays a unique set of spectral absorption lines much like a fingerprint in humans.

(b) (i) 9.5 ppm means that for each million parts of solution, 9.5 parts are lead.

(ii) 9.5 grams of lead in 1 000 000 grams of solution (assuming the solution has a density of 1 gram per mL).

$$\frac{9.5\text{ g}}{207.2\text{ g mol}^{-1}}\text{ in }1000\text{ L} = 4.6 \times 10^{-5}\text{ mol L}^{-1}.$$

45 (a) The same element having two or more different molecular or crystalline forms.

(b) 

oxygen ozone

(c) Oxygen molecules contain covalent bonds only; ozone molecules have covalent bonds as well as a coordinate covalent bond.

(d) Oxygen is a stable, odourless, colourless gas, slightly denser than air with a boiling point of –193°C. Ozone is an unstable, blue gas with a distinctive, sharp odour, 1.5 times denser than air. It has a boiling point of –111°C.

(e) The oxygen free radical is highly reactive; the oxygen molecule is stable.

46 (a) Hardness of water refers to the inability of water to form a reasonable lather with soap or detergent due to a high concentration of dissolved ions.

Turbidity of water refers to the amount of suspended materials within a water sample. The minute particles of the suspension scatter light in all directions thus making the water appear murky or translucent in appearance.

(b) Hardness is recorded as milligrams of $CaCO_3$ per litre of water. This can be determined by titrating the water sample with EDTA. This forms stable complexes with calcium and magnesium ions.

47 (a) Ozone is essential to living things on the Earth's surface. Ozone acts as a natural blockout to harmful UV radiation from the sun's rays. Because of its toxicity, ozone is also an effective antibacterial agent.

(b) Ozone is toxic to living organisms, including humans; concentrations as low as 0.2 ppm are dangerous.

(c) Ozone decomposes naturally to normal oxygen as it absorbs UV radiation. The action of CFCs speeds the decomposition of ozone. The CFCs decompose by the action of UV radiation to form free chlorine radicals. These radicals readily react with ozone decomposing it to normal oxygen.

Equation for CFCs depleting ozone from atmosphere:

$$CCl_2F_2(g) \xrightarrow{\text{light}} CClF_2(g) + Cl(g)$$

Chlorine atoms then catalyse the decompositon of ozone

$$Cl(g) + O_3(g) \rightarrow ClO(g) + O_2(g)$$

$$O(g) + ClO(g) \rightarrow Cl(g) + O_2(g)$$

$$O(g) + O_3(g) \rightarrow 2O_2(g)$$

48 Haber developed his process for the production of ammonia in Germany when the German government was preparing for World War I. Ammonia is a main reactant in the production of nitrogen compounds used for explosives. At this time there was also a shortage of fertilisers, also made from nitrogen compounds, because the main stocks came from South America and were expensive as well as taking a long time to get to Europe.

Haber and other chemists knew that the development of a process to convert atmospheric nitrogen to a useable product would be advantageous, especially in terms of cost, for industry and farming.

By 1913, Haber had developed a method of reacting atmospheric nitrogen with hydrogen gas in the presence of an iron catalyst that produced ammonia. This reaction allowed the German army to use ammonia to make the nitrogen compound necessary for explosives. Because of this, World War I was perhaps lengthened, as the Germans still had ready access to nitrogen compounds without needing to ship them from South America through the war-torn seas.

49 There are two main reasons to monitor the Haber process reaction vessel: to ensure that the catalyst surface is not poisoned and to ensure that there are no explosions.

- If the catalyst is not clean, there will be a very poor yield of the product, which wastes money and time. For this reason, the raw materials must be monitored to ensure they are clean, so as not to poison the catalyst or cause other, unwanted, reactions to occur.
- Extremely high temperatures can also permanently damage the catalyst, so these too must be monitored.
- CO_2 must be removed, usually by reaction with a base, to prevent side reactions occurring.
- It is particularly important that any oxygen present be removed, as this may cause an explosion with the hydrogen gas present.
- The reaction vessel is under high pressure and there is always a risk of explosion because of this. A technician should monitor the temperature and pressure on a regular basis.

Option Topic

Industrial Chemistry

Worked Answers

Question 1

(a) (i) To increase the rate of reaction

(ii) $K = [CO_2(g)]$

(iii) Larger.

The reaction is endothermic, therefore at higher temperatures the equilibrium position will lie further to the right.

(iv) The removal of the gaseous product lowers the pressure, forcing the reaction to proceed further towards completion.

(b) (i) Dehydrating agent eg ethanol → ethylene

Electrolyte eg in car batteries

Catalyst eg in esterification

(ii) When sulfuric acid is added to water, the ionisation occurs in two steps.

$H_2O(l) + H_2SO_4(l) \rightarrow H_3O^+(aq) + HSO_4^-(aq)$ STEP 1

$H_2O(l) + HSO_4^-(aq) \rightleftharpoons H_3O^+(aq) + SO_4^{2-}(aq)$ STEP 2

In the first step, a H–O bond is broken (endothermic) and a coordinate covalent bond between the hydrogen and a water molecule is formed (exothermic). The exothermic term is much larger than the endothermic term, hence the overall enthalpy change is negative. The same process occurs in the second ionisation step, but because the H^+ has to leave the HSO_4^- ion, which already has a negative charge, it is a weak acid and so the reaction occurs to a lesser extent.

(c) (i) $2NaCl + 2H_2O \rightleftharpoons 2NaOH + Cl_2 + H_2$

(ii) $2H_2O(l) + 2e^- \rightleftharpoons H_2(g) + 2OH^-(aq)$

(iii) $2Cl^-(aq) \rightleftharpoons Cl_2(g) + 2e^-$

(iv) Oxygen

(d) Salt (sodium chloride) and limestone (calcium carbonate)

(e) Marks will be awarded for

- naming a limited natural resource eg timber
- discussing issues associated with the increased need for the resource
- identifying replacement materials and/or current research into replacements
- choosing and using an appropriate text type, eg discussion (opening argument, discussion of issues and concluding remarks)

Question 2

(a) (i) (I) Production of sodium carbonate

(II) To recycle the ammonia

(ii) $NH_3(aq) + CO_2(g) + H_2O \rightleftharpoons NH_4^+(aq) + HCO_3^-(aq)$

$HCO_3^-(aq) + Na^+(aq) \rightleftharpoons NaHCO_3(s)$

(iii) The removal of carbon dioxide forces the reaction to proceed to the right; this increases the yield per unit time of sodium carbonate.

(iv) The Solvay process is exothermic. The main waste product is heat, which is transferred to the environment by cooling water, usually the lake that the salt was recovered from. This excess heat accelerates weed growth and may be harmful to other plants or animals in the lake. Another waste product is calcium chloride. Although this has economic importance, industry requires less calcium chloride than sodium carbonate, so the excess calcium chloride (and some excess sodium chloride) is usually dumped into the lake as well. The calcium ions react with carbonate and phosphate ions causing a precipitate on the bottom of the lake. Lake Onondoga in the USA has a two-metre thick artificial layer of limestone as a result of this precipitation process. These problems are being addressed by phasing out the Solvay process and replacing it with a process of purifying natural sources of sodium carbonate found in minerals.

(b) (i) Sodium hydroxide solution and castor oil (containing triglycerides) were combined in a beaker and gently boiled until the oil was no longer visible as a separate layer. The solution was cooled and stirred. Sodium chloride is added to precipitate the soap from solution. The products formed are sodium carboxylate (soap) and glycerol.

The main safety precautions are associated with sodium hydroxide as it is highly corrosive. Safety glasses must be worn. Wash any affected area of the body or clothing with running water. Do not use the final product on the skin unless excess NaOH has been neutralised.

(ii) Soaps have a polar (carboxylate functional group) end and a non polar (fatty acid) end. The polar end dissolves readily in water, while the non polar end dissolves fats. The soap allows the fats and water to be mixed together.

(c) (i) $Na^+ + e^- \rightarrow Na(l)$

(ii) The sodium/mercury amalgam is removed from the cell and sprayed onto water where sodium reacts to produce hydroxide.

$2Na + 2H_2O(l) \rightarrow 2Na^+ + 2OH^- + H_2(g)$

(iii) To form an amalgam with the sodium to prevent an explosive reaction with aqueous solution.

(iv) (I) It is difficult to control the loss of mercury into waterways. Mercury builds up in the food chain, especially in shellfish.

(II) The diaphragm cell.