ACJC solutions for H2 Chemistry Prelim Paper 2 2022

| 1 | (a) | Table 1.1 shows the solubility of two organic molecules at 25 °C. | | | | |
|---|-----|--|---|--|--|--|
| | | | Table 1.1 | | | |
| | | | solubility in water / g dm ⁻³ | | | |
| | | | propanone | miscibl | e | |
| | | | chloromethane | 5.04 | | |
| | | (i) Identify the type of | | of intermolecular force present | between the molecules. | |
| | | | propanone: | permanent dipole -perma | nent dipole | |
| | | | chloromethane:permanent dipole -permanent dipole[1] | | | |
| | | | Comments: Some studen between its m | nts thought that propanone nolecules. | has hydrogen bonding | |
| | | (ii) | Give a reason for | the difference in their solubilit | ies in water | |
| | | Propanone is able to form <u>hydrogen bonds with water</u> but chloromethane is unable to. | | | | |
| | | | Students nee bonds with the Students need when discuss Some student mixes very we | d to recognise that propanone e oxygen atom of propanone. d to highlight the differences in ing solubility differences. ts did not understand that misc ell with water. | e is able to form hydrogen solute-solvent interactions ible means that propanone | |
| | (b) | The | boiling point of thre | ee ligands are shown in Table | 1.2. | |
| | | | | Table 1.2 | | |
| | | | ligand | formula | boiling point / °C | |
| | | | water | H ₂ O | 100 | |
| | | | ammonia | NH ₃ | -33.3 | |
| | | | hydrazine | N ₂ H ₄ | 114 | |
| | | (i) | Explain what is m | eant by the term <i>ligand</i> . | | |
| | | | A ligand is a new electrons to form | utral molecule or anion speci- a <u>dative bond</u> with a central <u>m</u> | es that has a <u>lone pair</u> of <u>netal atom or ion.</u> | |

| | (ii) | Explain the difference in the boiling points of the three ligands. |
|-----|----------------------------|---|
| | | Hydrazine has the highest boiling point as it has the <u>largest/most</u> polarisable electron cloud size has <u>strongest instantaneous dipole-induced</u> <u>dipole</u> . |
| | | Water form more extensive hydrogen bonds than ammonia and hence it has a higher boiling point. |
| | | Comments: Students need to select and compare two molecules at each time, using the appropriate concept, rather than make general statements. Some students were confused about the electronegativity difference between nitrogen and oxygen. Some students wrongly thought that because hydrazine being a larger molecules will be able to form more extensive hydrogen bonds. Although hydrazine does have more hydrogens atoms that can be used to form hydrogen bonds, the limiting factor is the number of lone pair of electrons. Hydrazine has the same number of lone pair of electrons as water (2 x 1 on each N of hydrazine and 1 x 2 on O of water). |
| (c) | Poly | dentate ligands are ligands which form more than one bond with the metal |
| | Salio H ₂ sa | cylaldehyde, ethane-1,2-diamine and H ₂ salen are examples of such ligands. Ilen can be synthesised from salicylaldehyde and ethane-1,2-diamine. |
| | 2 | $ \bigcirc O \\ \bigcirc OH + H_2N \\ NH_2 $ $ \bigcirc OH HO $ $ + 2X $ |
| | salicy | /laldehyde ethane-1,2-diamine H ₂ salen |
| | Whe ligar | In the phenolic groups of H_2 salen are deprotonated, salen ^{2–} acts as a d. It has a high affinity for Co^{2+} ions and forms a planar complex Co(salen). |
| | (i) | Suggest the identity of molecule X . |
| | | H ₂ O |
| | | Comments: There is no need to write both 'water' and 'H₂O' in the answer as both responses refer to the same species. Either will do. |





| | Comments: Students need to recognise that the alkene is part of a cyclic structure since no carbon atoms were lost. This question proved to be demanding for many students, who did not recognise the positive iodoform test, in proposing their structure of B. |
|--|--|
| | [Total: 13] |

| 2 | Chromium is a transition metal that is values for its high resistance to corrosion and | | | | | |
|---|--|--|--|--|--|--|
| | is ac Whi | ile chromium can exist in various oxidation states, the most common oxidation | | | | |
| | state | e is the +3 state. | | | | |
| | | | | | | |
| | (a) | $CrCl_3.6H_2O$. One such isomer is $[CrCl_2(H_2O)_4]Cl_2H_2O$ and it appears dark green. | | | | |
| | | Suggest the formula of two other isomers of hydrated chromium (III) chloride. | | | | |
| | | isomer 1: | | | | |
| | | isomer 2:[2] | | | | |
| | | [CrC/ ₃ (H ₂ O) ₃].3H ₂ O | | | | |
| | | [CrC/(H ₂ O) ₅]C/ ₂ .H ₂ O [Cr(H ₂ O) ₆]Cl ₃ | | | | |
| | | | | | | |
| | | Comments: | | | | |
| | | To obtain the answer, students need to switch the ligands about the Cr³⁺ centre. | | | | |
| | | The coordination number of chromium should not change, given that these are isomers of the given compound. | | | | |
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| (:::) | Explain why solutions of transition motal compounds are often coloured |
|-------|--|
| (111) | |
| | The d orbitals are partially filled. |
| | In the presence of ligands, the degenerate d-orbitals/d-subshell are split into two groups of different energy levels. |
| | An electron in the lower energy level orbital can absorb energy equivalent to the energy gap which corresponds to a certain wavelength of light from the visible region of the electromagnetic spectrum and be promoted to the higher energy level orbital . |
| | The colour seen is complementary to the colour absorbed. |
| | Comments: Some answers did not highlight the importance of ligands in causing the splitting of the orbitals in the 3d subshell into 2 different energy levels. The idea that the colour observed is that which is reflected is incorrect. |
| | • Wavelengths of visible light that are not absorbed are transmitted through the solution, giving rise to the colour. |
| (iv) | Given that the oxidation state of chromium in compound D is still +3, suggest what happened that caused the colour change from green to violet. Ligand exchange occurred. |
| | The <u>energy gap</u> between lower energy level d orbitals and the higher energy level d orbitals <u>changed</u> and hence a different wavelength of visible light is absorbed. |
| | Comments: The change in the colour observed suggests that there is a change in the size of the energy gap. |
| | There are two main ways in which the energy gap changes – change in the oxidation state of the metal centre or change in the ligand. Since the question stated that the oxidation state of Cr is still +3, this means that colour change is due to a ligand exchange. Students should not describe the decrease/increase in the energy gap unless they are certain about the change. |
| (v) | State the role of H ₂ O ₂ (aq). |
| | [1] oxidising agent |
| | |
| | Comments: Students need to recognise that the oxidation state increased from +3 to +6 and hence H₂O₂ acted as an oxidising agent. This question was well answered. |
| | |

| | (vi) | Write a balanced equation for the formation of CrO_4^{2-} from C . |
|-----|----------------------------|---|
| | | [1] |
| | | $2[(Cr(OH)_6)]^{3-} + 3H_2O_2 \rightarrow 2CrO_4^{2-} + 2OH^- + 8H_2O$ OR |
| | | $2Na_3[(Cr(OH)_6)] + 3H_2O_2 \rightarrow 2Na_2CrO_4 + 2 NaOH + 8 H_2O$ |
| | | Comments: Several responses did not consider the medium in which the redox reaction occurred in. Students need to recognise that C was formed when an excess of NaOH was used, suggesting that the oxidation occurred in an alkaline medium. Some equations were constructed with electrons appearing on either side of the equation. Either the chemical or ionic equation is acceptable. |
| (c) | Fig. | 2.2 shows the first seven ionisation energies of calcium and chromium. |
| | ior e State calci | hisation heregy hisation heregy hisation heregy humber of electrons removed Fig. 2.2 e and explain which graph shows the successive ionisation energies for umber of electrons removed to variation in successive ionisation energies for umber of electrons removed to variation in successive ionisation energies for umber of electrons removed to variation in successive ionisation energies for umber of electrons removed to variation in successive ionisation energies for umber of electrons removed to variation in successive ionisation energies for umber of electrons removed to variation in successive ionisation energies for umber of electrons removed to variation in successive ionisation energies for umber of electrons removed to variation in successive ionisation energies for umber of electrons removed to variation in successive ionisation energies for umber of electrons removed to variation energies for umber of electrons removed to variation energies for constant of the successive ionisation energies for the successive ionisation energies f |
| | This the elect | is because there is a <u>large jump between the 2^{nd} and 3^{rd} IE showing that 3^{rd} electron is removed from an inner shell and the atom has 2 valence trons.</u> |
| | Con | ments: |
| | • C | dentify the correct graph. |
| | | [Total: 14] |



| | (ii) State the two properties of a gas necessary for it to approach ideal behaviour. | | | |
|-----|--|--|--|--|
| | | The gas must have negligible intermolecular forces of attraction. | | |
| | | There is <u>negligible size/volume of the gaseous molecules</u> /particles <u>compared to the size of the container/volume of gas</u> . | | |
| | | Comments: | | |
| | Some students gave the conditions under which real gases approach ideal behaviour. | | | |
| | | Students need to tell the difference between properties of the gas and the conditions under which the gas exhibits ideal behaviour. It is incorrect to say size of the <u>gas</u> was negligible compared to the size of the container. | | |
| | | Question asked for properties, not conditions. Students cannot interpret as conditions (high temperature and low pressure). | | |
| (b) | Orange street lamps contain sodium with a small amount of neon. The light is produced when gaseous atoms are ionised in an electric field. When it is first turned on, the lamps emit a red glow characteristic of neon, but after some time, the orange glow of sodium predominates. | | | |
| | Explain the order for the appearance of the colours. Use relevant data from the <i>Data Booklet</i> in your answer. [2] | | | |
| | The ionisation energy of <u>Na is 494 kJmol⁻¹</u> which is smaller than <u>Ne</u> which has an ionisation energy of <u>2080 kJmol⁻¹</u> . | | | |
| | However, <u>Na is a solid</u> at room temperature <u>needs to be vapourised</u> to Na(g) before ionization. OR Ne is already a gas at room temperature can be ionised immediately | | | |
| | Sinc obse | e time is required to vapourise the Na prior to ionisation, red glow of Ne is erved before the orange glow of sodium. | | |
| | Com • \$ • M F | Aments: Some responses mentioned successive ionisation energies. This is not the case since it will be energetically very difficult to remove them. Most responses were unable to recognise that the reason is because Na is present as a solid and hence needed to be vapourised first before ionisation could take place. | | |
| | | | | |



| | | (lodomethyl)benzene reacts much faster than (chloromethyl)benzene due to the weaker C–X bond and more stable X^- formed. |
|----------|--------------|--|
| | | <u>BE(C–I) 340 kJ mol⁻¹ is smaller than BE(C–C<i>l</i>) 240 kJ mol⁻¹. C–I bond is weaker than C–C<i>l</i>, hence (iodomethyl)benzene tends to react much faster than (chloromethyl)benzene.</u> |
| | | From the larger pK_b (or smaller K_b), I^- is a weaker base making it a good leaving group, I^- is a more stable conjugate base. Hence, I^- is formed more readily and hence (iodomethyl)benzene tends to react much faster than (chloromethyl)benzene. |
| | | Can explain in terms of chloride in the same way |
| | | Comments: |
| | | Most students are able to infer from the value of pK_b and relate to the base strength, leaving group. |
| | | Some students did not state the units when quoting the bond energy from Data Booklet. |
| (d) |) The Ado | first known synthesis of an amino acid occurred in 1850 in the laboratory of f Strecker. |
| | | $ \begin{array}{c} O \\ H \\ C \\ H \\ H$ |
| | | п R H ĊN ĊООН imine |
| | (i) | Name the type of reaction in step 1. |
| | | [1] |
| | | Condensation |
| | | Comments: |
| | | This reaction resembles <u>condensation</u> reaction between carbonyl and 2,4 DNPH. |
| 8- 0 | 5 | |
| R | H | $NH_3 \rightarrow R + NH_3 + NLH^2$ |
| R-C | 11H H | $+H_{20} \leftarrow R^{-C} \leftarrow H^{-L}$ |
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| | (ii) | With reference to the acid-base reaction mentioned in (c)(i), suggest why each of the following reactions does not take place in the presence of CH_3O^- . |
|--|------|---|
| | | (1) $CH_3CH_3 \longrightarrow {}^{-}CH_2CH_3$ (2) $CH_3COOH \longrightarrow {}^{-}CH_2COOH$ [2] |
| | | (1) The conjugate base of ethane is unstable as the electron-donating methyl group will intensify the negative charge. OR CH₃O⁻ is a more stable base than CH₃CH₂⁻ as the negative charge is stabilized by electronegative O atom in CH₃O⁻ |
| | | Comments: Some common wrong answers included No electron withdrawing group so -ve charge not dispersed. No delocalisation thus -ve charge not dispersed. |
| | | (2) The conjugate base formed -COO⁻ in deprotonating -COOH is more stable as negative charge is <u>delocalised over 2 electronegative O atoms</u>. OR O is more electronegative than C, hence stabilised negative charge more. |
| | | Comments: Some common wrong answers included |
| | | The conjugate base formed –COO ⁻ in deprotonating -COOH is <u>more</u> <u>stable</u> as negative charge is <u>delocalised into C=O group</u> . |
| | | Negative charge on carbon atom in ⁻ CH ₂ COOH <u>cannot be</u> <u>delocalised, unlike that on -COO⁻</u> where negative charge can be delocalised over 2 electronegative O atoms. |
| | | Reason for not accepting: even if the negative charge is on C of $^{-}$ CH ₂ COOH can also delocalise into C=O group. |
| | | Comments: Answers should focus on the differences in stabilities of the conjugate bases formed and explain how the structural differences in each species contribute to these stability differences. Poor answers only stated the differences in acidities between the species. |
| | | |





| (ii | When adjusted for standard conditions, an AFC is known to generate 1.23 V of electromotive force. With reference to the <i>Data Booklet</i> , write the half equation for each electrode and the overall equation. | | |
|------|--|--|--|
| | anode: H₂ + 2OH⁻ → 2H₂O + 2e cathode: O₂ + 2H₂O + 4e → 4OH⁻ overall: 2H₂ + O₂ → 2H₂O | | |
| (iii | Using information from (a)(ii), calculate the Gibbs free energy change per mol of water generated in the AFC. [1] | | |
| | ΔG = - NFE_{cell} = - (2)(96500)(1.23) = -237390 J mol⁻¹ = -237 kJ mol⁻¹ (3 s.f.) Comments: In the overall equation in (a)(ii), 2H₂ + O₂ + 4e → 2H₂O + 4e, so n(H₂O) : n(e) = 1 : 2 ∴ There are 2 mol of electrons exchanged per mol of water, therefore n = 2 Students are reminded to round off the answer to 3 significant figures and include suitable units | | |
| (iv |) Calculate the E_{cell}° of the PEM fuel cell. [2] | | |
| | E_{cell}^e = E_{cathode}^e - E_{anode}^e = 1.23 - 0.00 = +1.23 V Comments: The question states that the electrolyte of the PEM is acidic. Students may refer to half equations where H₂ is oxidised in acidic medium and O₂ is reduced in acidic medium Anode: H₂ → 2H⁺ + 2e E^e = 0.00 V Cathode: O₂ + 4H⁺ + 4e → 2H₂O E^e = +1.23 V | | |

| | (v) | Comment on the vo | Itages generated by th | ne AFC and PEN | A fuel cell. [1] |
|------|--|---|---|---|--|
| | | They have the <u>sar</u> <u>chemical reaction</u> , v Comments: • It is insufficie • Good answe the chemical | me voltage because which possesses the ent to state that the fu ers would relate the v | they undergo t same chemical of lel cells have the oltage to the ch | the <u>same overall</u> energy. e same voltage nemical energy of |
| (b) | The use (LO used At it meth meth | disadvantage of tran of hydrogen fuel co HC) such as the me d to transport hydrogen s source, hydrogen hylbenzene in the hylcyclohexane. Hydrogen | sporting hydrogen ga ells. More recently, l ethylbenzene / methy en safely over long dis is 'loaded' on the L e presence of p drogen is 'unloaded the catalyst to regene | s is one of the fa liquid organic h lcyclohexane sy stances. OHC by reactin latinum cataly ' from the LO rate methylbenz | actors limiting the hydrogen carriers /stem have been ng hydrogen with st to produce DHC by reacting zene. |
| | Tabl | e 5.1 contains inform | nation about methylbe | nzene and meth | nylcyclohexane. |
| | | liquids | density under conditions for transportation / kg m ⁻³ | boiling point at 1 atm / °C | flammability |
| | | hvdrogen | 71 | -252.9 | verv high |
| | r | nethylcyclohexane | 770 | 101 | high |
| | (i) | Write a balanced ed | quation for the loading | g of hydrogen or | n the LOHC. |
| | | + 3H ₂ Comments: • Students and organic com • Equations w | re reminded to use apounds written using molecula | structural form r formulae are n | ula to represent ot accepted |

| (ii) | State the type of catalyst used in the loading of the LOHC. Describe how it catalyses the reaction. | | |
|-------|---|--|--|
| | Heterogeneous catalyst. Hydrogen gas and methylbenzene adsorb on the surface of the platinum catalyst by forming weak bonds with the catalyst. Intramolecular covalent bonds are weakened, hence E_a is lowered when the reactants bond to the catalyst, allowing the reaction to occur more easily. Reactant molecules are brought into close contact at the catalyst surface. The <u>surface concentration of the reactants increases</u>, so the rate of reaction increases. Methylcyclohexane <u>desorb</u> from the surface of the catalyst, allowing more reactants to occupy the site. Comments: Students should not confuse between adsorption and diffusion or desorption and diffusion Desorption occurs after the reaction (not de-adsorption) Good answers describe how adsorption catalyses the reaction Weakening of covalent bonds in the reactants Higher surface area concentration of reactants | | |
| (iii) | Calculate the mass of H ₂ transported per m ³ of methylcyclohexane. | | |
| | Amount of methylcyclohexane per m ³ = 770 000 g m ⁻³ \div 98 g mol ⁻¹ = 7857 mol Amount of hydrogen per m ³ of methylcyclohexane = 7857 x 3 = 23571 mol Mass of hydrogen per m ³ of methylcyclohexane = 23571 mol m ³ x 2 g mol ⁻¹ = 47142 g m ⁻³ = 47.1 kg m ⁻³ (3 s.f.) | | |
| (iv) | Suggest whether it is advantageous for the transport of hydrogen to be changed from liquid hydrogen to the use of LOHC. | | |
| | This share is a description of 1010 is large flammable (large | | |
| | This change is advantageous as LOHC is less frammable / less explosive than hydrogen. OR This change is advantageous because LOHC has a higher boiling point / it is in the liquid state at room conditions, so it can be transported without cooling OR high pressure unlike H ₂ . OR This change is not advantageous as LOHC has a lower mass (or less) of hydrogen gas transported per unit volume. Comments: • Answer to this question must compare LOHC and H ₂ | | |

| | | Students should make use of data in table 5.1 and (b)(iv) for the comparison |
|-----|--------------------------------------|--|
| (c) | The on th rene of w hydr | hydrogen supply for fuel cells have been classified according to its impact ne environment. Green hydrogen refers to the gas that is produced using wable energy, without greenhouse gas emissions. For example, electrolysis vater powered by solar, wind or geothermal energy produces green ogen. |
| | (i) | Currently the most common method for generating hydrogen gas involves two successive reactions: 1) steam-methane reformation 2) water gas shift reaction |
| | | Using this method, methane reacts with steam to form four times the amount of hydrogen gas along with a side product. |
| | | Write the overall balanced equation for the above method[1] |
| | | $CH_4 + 2H_2O \rightarrow 4H_2 + CO_2$ |
| | | Comments: The following phrase in the question is important in solving this question "methane reacts with steam to form four times the amount of hydrogen gas along with a side product" Only answers that abided by this statement were accepted |
| | (ii) | Hence suggest whether the method in (c)(i) is a source of green hydrogen. [1] |
| | | It is not a source of green hydrogen as the greenhouse gas CO ₂ is formed. |
| | | Based on the equation in (c)(i), it is well recognized that the greenhouse gas CO₂ is formed. Thus, hydrogen formed from this method is not green hydrogen. |
| | (iii) | Hydrogen produced by steam-methane reformation may contain trace contaminants such as ethene. Draw the dot-and-cross diagram of ethene. State the bond angle and shape around the carbon atom. |
| | | Bond angle: 120° Shape: Trigonal planar H +. C : C + H H H H Comments: |
| | | Comments. |

| | • Draw the dot-and-cross diagram, and determine that shape and bond angle based on VSEPR Theory. | | | |
|-----|--|--|--|--|
| | [2] | | | |
| (d) | Electric vehicles (EVs) have been known as a greener form of transportation than petrol powered vehicles because greenhouse gases are not emitted from EVs. | | | |
| | By considering the source of the electrical energy, comment on the validity of this claim. | | | |
| | [1] | | | |
| | The claim is <u>valid</u> because using <u>renewable sources of energy such as solar</u> , wind or geothermal energy to generate electricity <u>does not release greenhouse</u> gases. | | | |
| | OR | | | |
| | The claim is <u>not valid</u> since the <u>burning of fossil fuels / fuels / coal</u> to generate electricity <u>releases greenhouse gases</u> . | | | |
| | Comments: • Good answers make reference to the power source for generating electricity • Either fossil fuels or coal whereby greenhouse gases are emitted • Or solar, wind or geothermal power whereby no greenhouse gases are emitted | | | |
| | Further information about electric vehicles: Watch CNA Insider 'Switching To Electric Car: Is It Worth It?' <u>https://youtu.be/cc9iYjPLnFM?t=693</u> | | | |
| | [Total: 19] | | | |