
2021 HSC Chemistry Exam Solutions
Section I: Multiple Choice Questions

1. A

At equilibrium, the rate of the forward and reverse reactions are equal.

2. B

Cl^- ions would react with Ag^+ ions to form a white precipitate (AgCl).

3. A

The compound is a secondary amide. The longest carbon chain with the amide functional group has 3 C atoms. There is a methyl ($-\text{CH}_3$) substituent attached to the N atom, so the name of the compound is *N*-methylpropanamide.

4. C

Ethyl pentanoate would be produced from ethanol and pentanoic acid.

5. B

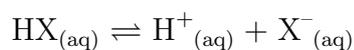
The burette should have also been rinsed with the NaOH solution. Since the burette was only rinsed with water, the NaOH would be more dilute than expected. Furthermore, the conical flask should have only been rinsed with distilled water. Rinsing it with CH_3COOH would increase the moles of CH_3COOH in the flask.

During the titration, a larger volume of NaOH would be needed from the burette to reach the end point than expected, since the NaOH has been diluted, and there are more moles of CH_3COOH in the conical flask that needs to be neutralised. This would lead to an overestimation of the CH_3COOH concentration.

6. C

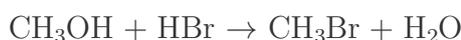
Temperature is the only factor that can affect the value of K , so dilution of a weak acid at constant temperature would have no effect on its K_a value.

Weak acids only partially ionise in water to form H^+ ions.



When the acid is diluted, $[HX]$, $[H^+]$ and $[X^-]$ will all decrease, so Le Chatelier's principle predicts that the equilibrium will shift towards the right, where there are more aqueous particles to counteract the change. This increases the degree of ionisation of the weak acid.

7. A



CH_3OH is a polar molecule that is capable of forming strong hydrogen bonds due to its polar $-OH$ group. CH_3Br is also polar, but it can not form hydrogen bonds. Instead, it forms weaker dipole-dipole forces which require less energy to overcome than the hydrogen bonds formed by methanol. This causes CH_3Br to have a lower BP than CH_3OH .

8. D

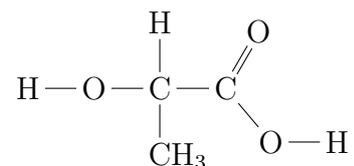
The non-polar, hydrophobic tail of soap would be embedded in the non-polar oil particles through dispersion forces. The polar, hydrophilic head of soap would interact with water via ion-dipole forces.

9. D

Paracetamol strongly absorbs light at 250 nm so it would be the ideal wavelength to use for the analysis. The solvent should NOT strongly absorb at 250 nm so that it doesn't interfere with the absorbance at 250 nm. The solvent that has minimal absorption at 250 nm is solvent *D*.

10. B

The polymer is a condensation polymer that contains the ester ($-COO-$) functional group. The monomer used to produce this polyester would therefore contain a hydroxyl ($-OH$) and carboxyl ($-COOH$) group. Cutting the ester linkage and inserting water back in leads to:



which is equivalent to option B.

11. C

The addition of a pure solid into an equilibrium mixture will have no effect on the equilibrium position because the concentration of a pure solid is constant.

12. A

The molecular ion peak is at $m/z = 98$, so the molar mass of the compound is 98 g mol^{-1} . There are 4 signals on the ^{13}C NMR spectrum which indicates 4 C environments. The signal at 209 ppm indicates a C=O group in an aldehyde or ketone. This data is consistent with compound A which is a ketone with 4 C environments (due to symmetry) and a molar mass of:

$$M(\text{C}_6\text{H}_{10}\text{O}) = (6 \times 12.01 + 10 \times 1.008 + 16.00) \text{ g mol}^{-1} = 98.14 \text{ g mol}^{-1}$$

13. C

Prop-1-ene is hydrated to form propan-2-ol as the major product by Markovnikov's rule. Propan-2-ol is a secondary alcohol that is oxidised to a ketone (propan-2-one).

14. D



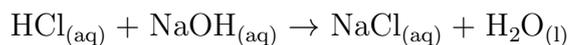
When $A = 0.30$, $[\text{Ni}^{2+}] = 0.0021 \text{ mol L}^{-1}$.

$$\begin{aligned} n(\text{Ni}^{2+}) &= 0.0021 \text{ mol L}^{-1} \times 0.2500 \text{ L} \\ &= 5.25 \times 10^{-4} \text{ mol} \end{aligned}$$

These moles came from a 10.00 mL solution of the original 50.00 mL sample. Therefore, the moles of Ni^{2+} in the original sample is given by:

$$\begin{aligned} n(\text{Ni}^{2+}) &= 5 \times 5.25 \times 10^{-4} \text{ mol} \\ &= 2.625 \times 10^{-3} \text{ mol} \\ n(\text{Ni}) &= 2.625 \times 10^{-3} \text{ mol} \\ m(\text{Ni}) &= 2.625 \times 10^{-3} \text{ mol} \times 58.69 \text{ g mol}^{-1} \\ &= 0.15 \text{ g} \end{aligned}$$

15. B



$$\begin{aligned} n(\text{HCl}) &= 0.20 \text{ mol L}^{-1} \times 0.020 \text{ L} \\ &= 4.0 \times 10^{-3} \text{ mol} \end{aligned}$$

$$\begin{aligned} n(\text{NaOH}) &= 0.50 \text{ mol L}^{-1} \times 0.020 \text{ L} \\ &= 0.010 \text{ mol} \end{aligned}$$

HCl is the limiting reagent while NaOH is in excess.

$$\begin{aligned} n(\text{NaOH}) \text{ leftover} &= 0.010 \text{ mol} - 4.0 \times 10^{-3} \text{ mol} \\ &= 6.0 \times 10^{-3} \text{ mol} \end{aligned}$$

$$n(\text{OH}^-) \text{ leftover} = 6.0 \times 10^{-3} \text{ mol}$$

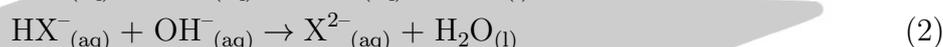
$$\begin{aligned} [\text{OH}^-] &= \frac{6.0 \times 10^{-3} \text{ mol}}{(0.020 + 0.020) \text{ L}} \\ &= 0.15 \text{ mol L}^{-1} \end{aligned}$$

$$\begin{aligned} \Rightarrow \text{pOH} &= -\log_{10}(0.15) \\ &= 0.82 \end{aligned}$$

$$\begin{aligned} \Rightarrow \text{pH} &= 14.00 - 0.82 \\ &= 13.2 \end{aligned}$$

16. B

The titration curve has 2 equivalence points so it is a diprotic acid with 2 acidic protons. The following step-wise neutralisation reactions would occur:



The equivalence point at 10 mL is reached when reaction (1) has occurred stoichiometrically while the equivalence point at 20 mL is reached when reaction (2) has occurred stoichiometrically.

17. D

$$\begin{aligned} n((\text{NH}_4)_3\text{PO}_4 \cdot 12 \text{MoO}_3) &= \frac{24.21 \text{ g}}{1877 \text{ g mol}^{-1}} \\ &= 0.01290 \text{ mol} \end{aligned}$$

1 mole of $(\text{NH}_4)_3\text{PO}_4 \cdot 12 \text{MoO}_3$ contains 1 mole of PO_4^{3-} .

$$\Rightarrow n(\text{PO}_4^{3-}) = 0.01290 \text{ mol}$$



$$n(\text{Na}_3\text{PO}_4) = 0.01290 \text{ mol}$$

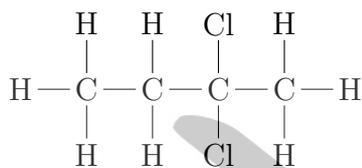
$$\begin{aligned} m(\text{Na}_3\text{PO}_4) &= 0.01290 \text{ mol} \times (3 \times 22.99 + 30.97 + 4 \times 16.00) \text{ g mol}^{-1} \\ &= 2.115 \text{ g} \end{aligned}$$

18. D

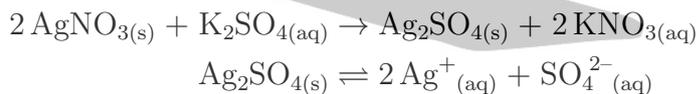
There are 3 signals on the ^1H NMR spectrum, so there are 3 ^1H environments and these are summarised below:

- The signal at 1.0 ppm has an integration of 3 and is a triplet (3) which indicates a $\text{CH}_3\text{—CH}_2\text{—}$ group.
- The signal at 1.4 ppm has an integration of 3 and is a singlet (1) which indicates an isolated $\text{CH}_3\text{—}$ group.
- The signal at 1.8 ppm has an integration of 2 and is a quartet (4) which indicates a $\text{CH}_3\text{—CH}_2\text{—}$ group.

The only compound consistent with this information is 2,2-dichlorobutane.



19. C.



A precipitate would start to form at the saturation point when $Q_{\text{sp}} = K_{\text{sp}} = 1.20 \times 10^{-5}$. Assuming that solid AgNO_3 was added and the volume of the solution remains constant,

$$\begin{aligned}
 Q_{\text{sp}} &= [\text{Ag}^+]^2[\text{SO}_4^{2-}] \\
 1.20 \times 10^{-5} &= [\text{Ag}^+]^2 \times 0.100 \\
 \Rightarrow [\text{Ag}^+] &= 0.0110 \text{ mol L}^{-1} \\
 n(\text{Ag}^+) &= 0.0110 \text{ mol L}^{-1} \times 0.2500 \text{ L} \\
 &= 2.74 \times 10^{-3} \text{ mol} \\
 n(\text{AgNO}_3) &= 2.74 \times 10^{-3} \text{ mol} \\
 m(\text{AgNO}_3) &= 2.74 \times 10^{-3} \text{ mol} \times 169.9 \text{ g mol}^{-1} \\
 &= 0.465 \text{ g}
 \end{aligned}$$

20. C

$$[\text{H}_3\text{O}^+]_{\text{eq}} = 10^{-4.46} \text{ mol L}^{-1}$$

	$(\text{CH}_3)_3\text{NH}^+$	H_3O^+	$(\text{CH}_3)_3\text{N}$
Initial	<i>N/A</i>	0	0
Change	<i>N/A</i>	$+10^{-4.46}$	$+10^{-4.46}$
Equilibrium	<i>x</i>	$10^{-4.46}$	$10^{-4.46}$

$$K_a = \frac{[\text{H}_3\text{O}^+][(\text{CH}_3)_3\text{N}]}{[(\text{CH}_3)_3\text{NH}^+]}$$

$$1.55 \times 10^{-10} = \frac{10^{-4.46} \times 10^{-4.46}}{x}$$

$$\Rightarrow x = 7.75 \text{ mol L}^{-1}$$

$$= [(\text{CH}_3)_3\text{NH}^+]_{\text{sat}}$$



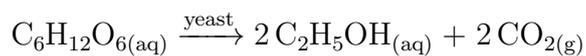
$$[\text{Cl}^-]_{\text{sat}} = 7.75 \text{ mol L}^{-1}$$

$$K_{\text{sp}} = [(\text{CH}_3)_3\text{NH}^+][\text{Cl}^-]$$

$$= 7.75 \times 7.75$$

$$= 60.2$$

Question 25



$$n(\text{CO}_2) = \frac{1.006 \text{ L}}{24.79 \text{ L mol}^{-1}}$$

$$= 0.04058 \text{ mol}$$

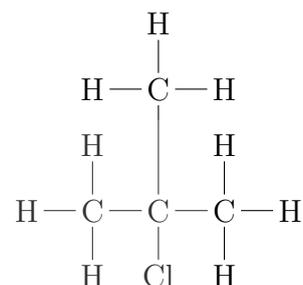
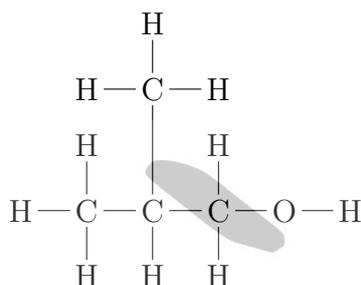
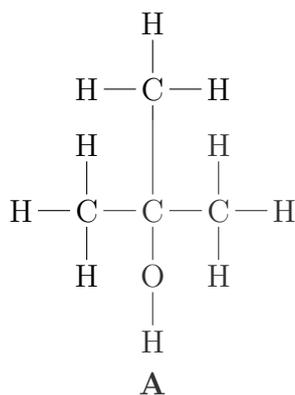
$$n(\text{C}_2\text{H}_5\text{OH}) = 0.04058 \text{ mol}$$

$$m(\text{C}_2\text{H}_5\text{OH}) = 0.04058 \text{ mol} \times (2 \times 12.01 + 6 \times 1.008 + 16.00) \text{ g mol}^{-1}$$

$$= 1.869 \text{ g}$$

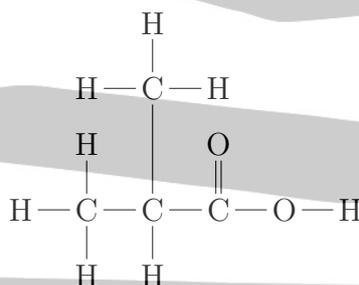
Question 26

(a)



B

C



D

- (b) Refluxing allows for higher temperatures to be used for a faster reaction rate without the loss of any volatile substances. The refluxing apparatus is also safe since it is open to the atmosphere and there will not be a dangerous build-up of gas pressure during heating.

Question 27

For sample 3, $Q_{\text{sp}} < K_{\text{sp}}$ since no precipitate forms.

$$\begin{aligned} Q_{\text{sp}} &= [\text{Li}^+]^3[\text{PO}_4^{3-}] \\ &= 0.15^3 \times 0.010 \\ &= 3.4 \times 10^{-5} \end{aligned}$$

Similarly, for sample 4, $Q_{\text{sp}} > K_{\text{sp}}$ since a precipitate forms.

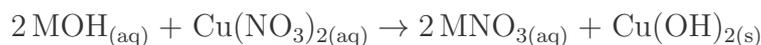
$$\begin{aligned} Q_{\text{sp}} &= 0.15^3 \times 0.10 \\ &= 3.4 \times 10^{-4} \end{aligned}$$

The most narrow range for K_{sp} is therefore $3.4 \times 10^{-5} < K_{\text{sp}} < 3.4 \times 10^{-4}$.

(b) Additional samples with $[\text{Li}^+] = 0.15 \text{ mol L}^{-1}$ and a $[\text{PO}_4^{3-}]$ in between that of 0.010 mol L^{-1} and 0.10 mol L^{-1} can be tested. This would narrow down the range within which K_{sp} lies, increasing accuracy.

Question 28

Let the alkali metal hydroxide be denoted as MOH where M is a group 1 metal.



$$\begin{aligned} n(\text{Cu}(\text{OH})_2) &= \frac{4.61 \text{ g}}{(63.55 + 2(16.00 + 1.008)) \text{ g mol}^{-1}} \\ &= 0.0473 \text{ mol} \end{aligned}$$

$$\begin{aligned} n(\text{MOH}) &= 2 \times 0.0473 \text{ mol} \\ &= 0.0945 \text{ mol} \end{aligned}$$

$$\begin{aligned} M(\text{MOH}) &= \frac{5.30 \text{ g}}{0.0945 \text{ mol}} \\ &= 56.1 \text{ g mol}^{-1} \end{aligned}$$

$$\begin{aligned} \Rightarrow M(\text{M}) &= (56.1 - 16.00 - 1.008) \text{ g mol}^{-1} \\ &= 39.1 \text{ g mol}^{-1} \\ &= M(\text{K}) \end{aligned}$$

\therefore The metal hydroxide is potassium hydroxide (KOH).

Question 29IR spectrum

- The medium absorption at $3300 - 3500 \text{ cm}^{-1}$ indicates the presence of a N–H (amine) group. Two absorptions bands are observed due to the symmetric and asymmetric N–H stretch.

Mass spectrum

- The peak at $m/z = 30$ indicates a CH_2NH_2^+ fragment ion that was formed from fragmentation of the unstable molecular ion. This fragment is indeed present in the provided molecule.

 ^{13}C NMR spectrum

There are 3 signals on the ^{13}C NMR spectrum, so there are 3 C environments which is consistent with the symmetrical structure of pentane-1,5-diamine.

- The signal at 25 ppm represents the central C environment ($-\text{CH}_2-$).
- The signal at 34 ppm represents the 2 C environments ($2 \times -\text{CH}_2-$) adjacent to the central C atom.
- The signal at 42 ppm represents the 2 deshielded C–N environments.

 ^1H NMR spectrum

The signal at 1.3 ppm is actually composed of 2 signals which are both quintets. One of these signals would have an integration of 2H which corresponds with the $-\text{CH}_2-$ proton environment in the middle of the molecule. This proton environment has 4 proton neighbours adjacent to it which causes the signal to be split into a quintet by the $n + 1$ rule of spin-spin coupling.



The other signal would have an integration of 4H which corresponds with the 2 equivalent $-\text{CH}_2-$ proton environments directly adjacent to the central C atom. These proton environments also have 4 proton neighbours adjacent to them, resulting in a quintet.

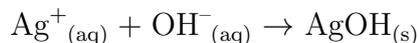


Both of these environments produce signals with very similar chemical shifts which causes the signals to overlap on the spectrum, resulting in a total integration of $4\text{H} + 2\text{H} = 6\text{H}$. The relatively low chemical shift of 1.3 ppm indicates these proton environments are not in close proximity to the deshielding $-\text{NH}_2$ groups.

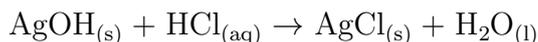
Question 30

The addition of NaCl would not help identify the ions as the Na^+ ion does not precipitate with OH^- or CH_3COO^- , and the Cl^- ion does not precipitate with Ba^{2+} , Ca^{2+} or Mg^{2+} . It does, however, eliminate the possibility of Ag^+ or Pb^{2+} ions being in the sample.

The addition of AgNO_3 can help identify the presence of OH^- since a brown precipitate of AgOH would form:

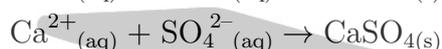
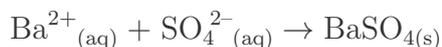


The brown precipitate (which is basic) dissolving in HCl also helps confirm the presence of OH^- .



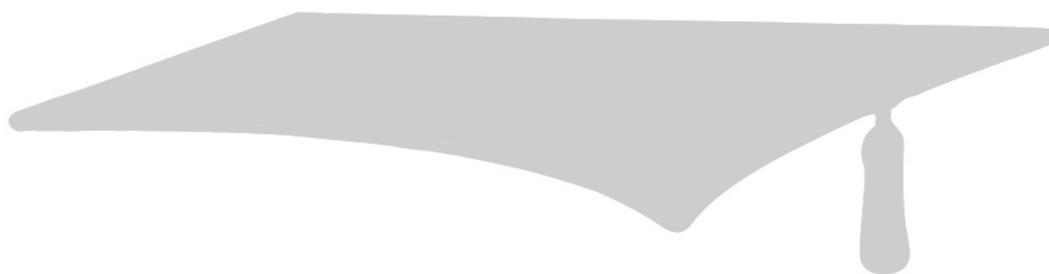
AgCH_3COO is a sparingly water soluble white salt that can be easily distinguished from the brown AgOH precipitate.

When Na_2SO_4 is added, a white precipitate forms, but this can either be due to the presence of Ba^{2+} or Ca^{2+} ions.



Both BaSO_4 and CaSO_4 are white precipitates so it would not be possible to differentiate between them visually.

As such, the student's procedure would allow him to identify OH^- ions in the solution, but it would NOT be effective at identifying the cation present in the solution. Furthermore, if the solution contains a mixture of cations and anions, the student did not perform enough tests to identify any remaining ions (Mg^{2+} or CH_3COO^-) that might be in solution.



Question 31

$$\begin{aligned}
 [\text{N}_2]_{\text{eq,i}} &= \frac{4.50 \text{ mol}}{10.0 \text{ L}} \\
 &= 0.450 \text{ mol L}^{-1}
 \end{aligned}$$

Similarly,

$$\begin{aligned}
 [\text{H}_2]_{\text{eq,i}} &= 0.100 \text{ mol L}^{-1} \\
 [\text{NH}_3]_{\text{eq,i}} &= 0.580 \text{ mol L}^{-1} \\
 [\text{NH}_3]_{\text{eq,f}} &= \frac{5.80 \text{ mol} + 0.050 \text{ mol}}{10.0 \text{ L}} \\
 &= 0.585 \text{ mol L}^{-1}
 \end{aligned}$$

	N_2	H_2	NH_3
Initial	$0.450 + x$	0.100	0.580
Change	-2.50×10^{-3}	-7.50×10^{-3}	$+5.00 \times 10^{-3}$
Equilibrium	$0.4475 + x$	0.0925	0.585

$$K = \frac{[\text{NH}_3]^2}{[\text{N}_2][\text{H}_2]^3}$$

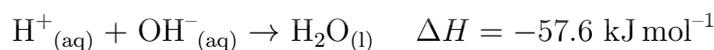
$$748 = \frac{0.585^2}{(0.4475 + x) \times 0.0925^3}$$

$$\implies x = 0.13 \text{ mol L}^{-1}$$

$$\begin{aligned}
 \implies n(\text{N}_2)_{\text{added}} &= 0.13 \text{ mol L}^{-1} \times 10.0 \text{ L} \\
 &= 1.3 \text{ mol}
 \end{aligned}$$

Question 32

In the first 2 reactions, a strong acid (HCl and HNO_3) that is fully ionised to H^+ is being reacted with a strong base (KOH) that is fully dissociated to OH^- . As such, the enthalpy changes are the same because the overall net ionic equation is the same in both cases:



In the third reaction, a weak acid (HCN) is being reacted with a strong base (KOH). The weak acid is not initially fully ionised in solution. During the weak acid-strong base neutralisation reaction, some energy is absorbed to break the $\text{H}-\text{C}$ covalent bond to force the weak acid to completely ionise and react. This causes the overall enthalpy change for the last reaction to have a lower magnitude than 57.6 kJ mol^{-1} (i.e. less heat is released).

Question 33

(a)

$$\begin{aligned}
 \Delta G &= \Delta H - T\Delta S \\
 &= -95 \text{ kJ mol}^{-1} - -80 \text{ kJ mol}^{-1} \\
 &= -15 \text{ kJ mol}^{-1}
 \end{aligned}$$

- (b) For this system, $\Delta H < 0$ (exothermic) which is thermodynamically favourable, while $T\Delta S < 0$ (entropy decreases) which is thermodynamically unfavourable. The sign of ΔG and thus the spontaneity of the reaction would depend on the relative magnitudes of ΔH and $T\Delta S$.

At T_1 , the negative ΔH term outweighs the $T\Delta S$ term in magnitude, resulting in $\Delta G < 0$ and thus the forward reaction would occur spontaneously.

At T_2 , $\Delta H = T\Delta S$, so $\Delta G = 0$. This indicates the system is at equilibrium at T_2 .

At T_3 , the negative $T\Delta S$ term outweighs the ΔH term in magnitude, resulting in $\Delta G > 0$ and thus the forward reaction would not occur spontaneously.

Question 34

At t_0 , the pH of water is 7 since water is a neutral substance. The pH of solutions X and Y are at 5 which indicates that these solutions are acidic. When HCl is bubbled through water, the HCl ionises to form H_3O^+ , causing an increase in $[\text{H}_3\text{O}^+]$ and a decrease in the pH of all the solutions.



It is notable that the pH of solutions X and Y do not decrease significantly from t_0 to t_1 . This is most likely because X and Y are buffer solutions that contain similar amounts of a weak acid and its conjugate base which can resist changes in pH when HCl is added to them. A buffering effect would result in the solutions having roughly the same pH at t_1 . By t_2 , the pH of solution X has decreased significantly more than Y . This indicates that solution Y has a higher buffering capacity than X , most likely due to Y having a higher concentration of the weak acid and its conjugate base present. However, the ratio of the concentration of the weak acid and conjugate base in solutions X and Y must be the same for both solutions to have the same initial pH of 5 at t_0 .

For water, the pH drops significantly from t_0 to t_1 to t_2 since water cannot act as a buffer and it would not resist changes in pH when HCl is added to it. The pH changes begin to flatten out at t_2 due to the logarithmic nature of the pH scale.

Question 35

Taking an average of the concordant titres (2 and 4, ± 0.10 mL).

$$V(\text{S}_2\text{O}_3^{2-}) = \frac{0.0287 \text{ L} + 0.0286 \text{ L}}{2}$$

$$= 0.02865 \text{ L}$$

$$n(\text{S}_2\text{O}_3^{2-}) = 0.900 \text{ mol L}^{-1} \times 0.02865 \text{ L}$$

$$= 0.0258 \text{ mol}$$

$$n(\text{I}_2) = \frac{1}{2} \times 0.0258 \text{ mol}$$

$$= 0.0129 \text{ mol}$$

$$n(\text{Cr}_2\text{O}_7^{2-})_{\text{leftover}} = \frac{1}{3} \times 0.0129 \text{ mol}$$

$$= 4.30 \times 10^{-3} \text{ mol}$$

$$n(\text{Cr}_2\text{O}_7^{2-})_{\text{added}} = 0.500 \text{ mol L}^{-1} \times 0.0200 \text{ L}$$

$$= 0.0100 \text{ mol}$$

$$n(\text{Cr}_2\text{O}_7^{2-})_{\text{reacted}} = n(\text{Cr}_2\text{O}_7^{2-})_{\text{added}} - n(\text{Cr}_2\text{O}_7^{2-})_{\text{leftover}}$$

$$= 0.0100 \text{ mol} - 4.30 \times 10^{-3} \text{ mol}$$

$$= 5.70 \times 10^{-3} \text{ mol}$$

$$n(\text{C}_2\text{H}_5\text{OH}) = \frac{3}{2} \times 5.70 \times 10^{-3} \text{ mol}$$

$$= 8.55 \times 10^{-3} \text{ mol}$$

$$m(\text{C}_2\text{H}_5\text{OH}) = 8.55 \times 10^{-3} \text{ mol} \times (2 \times 12.01 + 6 \times 1.008 + 16.00) \text{ g mol}^{-1}$$

$$= 0.394 \text{ g}$$

$$V(\text{C}_2\text{H}_5\text{OH}) = \frac{0.394 \text{ g}}{0.789 \text{ g mL}^{-1}}$$

$$= 0.500 \text{ mL}$$

$$[\text{C}_2\text{H}_5\text{OH}]_{\text{diluted}} = \frac{0.500 \text{ mL}}{25.00 \text{ mL}} \times 100\%$$

$$= 2.00\% \text{ v/v}$$

However, the ethanol was diluted 40-fold before the titration.

$$\Rightarrow [\text{C}_2\text{H}_5\text{OH}]_{\text{undiluted}} = 40 \times 2.00\%$$

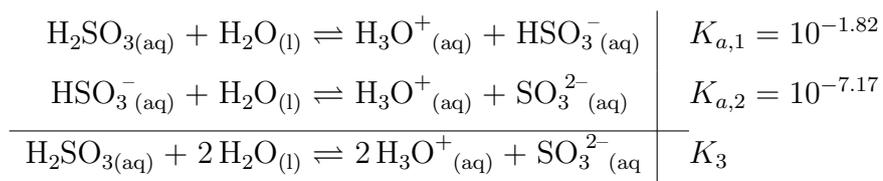
$$= 79.9\% \text{ v/v}$$

$$< 85\% \text{ v/v}$$

\therefore The sample does NOT meet the manufacturer's requirements.

Question 36

Note that when 2 equilibrium equations are added, the equilibrium constant of the overall equation is the product of the K values of the individual equations.



$$\begin{aligned}
 K_{a,1} &= \frac{[\text{H}_3\text{O}^+][\text{HSO}_3^-]}{[\text{H}_2\text{SO}_3]} \\
 K_{a,2} &= \frac{[\text{H}_3\text{O}^+][\text{SO}_3^{2-}]}{[\text{HSO}_3^-]} \\
 K_3 &= \frac{[\text{H}_3\text{O}^+]^2[\text{SO}_3^{2-}]}{[\text{H}_2\text{SO}_3]} \\
 &= \frac{[\text{H}_3\text{O}^+][\text{HSO}_3^-]}{[\text{H}_2\text{SO}_3]} \times \frac{[\text{H}_3\text{O}^+][\text{SO}_3^{2-}]}{[\text{HSO}_3^-]} \\
 &= K_{a,1} \times K_{a,2} \\
 &= 10^{-1.82} \times 10^{-7.17} \\
 &= 1.0 \times 10^{-9}
 \end{aligned}$$