HWA CHONG INSTITUTION
2019 C2 H2 CHEMISTRY PRELIMINARY EXAM
SUGGESTED SOLUTIONS

Paper 1

ANSWERS:

1	2	3	4	5	6	7	8	9	10
D	**A**	**D**	**B**	**C**	**C**	**A**	**B**	**C**	**B**
11	12	13	14	15	16	17	18	19	20
B	**B**	**B**	**A**	**C**	**D**	**A**	**B**	**C**	**C**
21	22	23	24	25	26	27	28	29	30
D	**D**	**D**	**A**	**C**	**B**	**A**	**C**	**D**	**C**

Comments

1 D

The definition for atomic mass is the ratio of the average mass of one atom of an element to one-twelfth the mass of one atom of ^{12}C. In option **D**, the mass of one mole of atoms of an element has already taken into account all the isotopes and their relative abundances.

2 A

The electronegativity increases across Period 3 as the effective nuclear charge increases.

The electrical conductivity of the metals Na to A*l* increases while Si is a semiconductor and the non-metals P, S and C*l* are non-conductors.

The atomic radii across Period 3 shows a generally decreasing trend due to the increase in effective nuclear charge across the period.

The melting point increases from Na to A*l* on account of the increasing metallic bonding strength; the trend peaks at Si which has a giant covalent structure with extensive strong covalent bonding, before showing a decreasing trend for the simple covalent compounds which only have weak dispersion forces between molecules.

3 D

Ice has a simple covalent structure. There is hydrogen bonding between water molecules, and covalent bonding between atoms of H and O in each molecule of water.

Iodine has a simple covalent structure. There are dispersion forces between iodine molecules, and covalent bonding between atoms of iodine in each molecule of iodine.

Aluminium chloride has an ionic lattice structure with a large amount of covalency in the solid state at room temperature. Its structure becomes simple covalent just below its melting point resulting in dispersion forces between Al_2Cl_6 molecules. Hence permanent dipole interactions are not found in the solid state.

Graphite has a giant covalent structure with dispersion forces holding the sheets of carbon atoms together.

4 B

Species	**NH_4^+**	**XeF_4**
Shape	Tetrahedral	Square planar
Bond Angle	109.5^o	90^o
Species	**NF_3**	**NH_3**
Shape	Trigonal pyramidal	Trigonal pyramidal
Bond Angle	102^o	107^o
	F is more electronegative than N and so the electron cloud of the N–F bond is distorted towards F. This causes the electron density about N to decrease. Thus, bond pair-bond pair repulsion is weaker around the central N atom in NF_3 than in NH_3. Hence, bond angle in NF_3 is smaller.	
Species	**NO_2^+**	**SO_2**
Shape	Linear	Bent
Bond Angle	180^o	$<120^o$
Species	**BCl_3**	**PCl_3**
Shape	Trigonal planar	Trigonal pyramidal
Bond Angle	120^o	107^o

5 C

Since the number of moles of gas in the three containers did not change before and after the taps are opened, the number of moles of gas found in the individual containers before and after the taps are opened should be the same.

$$\eta_{\text{gas in first container}} + \eta_{\text{gas in second container}} + \eta_{\text{gas in third container}} = \eta_{\text{gas in overall container}}$$

Note that there is no gas in the second container since it contains a vacuum. Thus it is not included in the calculation of the total number of moles of gas.

$$\frac{P_1V_1}{T_1} + \frac{P_2V_2}{T_2} = \frac{P_{final} \times V_{final}}{T_{final}}$$

$$\frac{1 \times 420}{293} + \frac{2 \times 75.5}{273} = \frac{P_{final} \times (420 + 75.5 + 13)}{298}$$

P_{final} = 1.16 bar

6 **C**

No. of moles of sodium percarbonate = 10.0 x 10^{-3} x 0.100 = 0.00100

1 mole of sodium percarbonate produces x moles of CO_2.
No. of moles of carbon dioxide = 48 ÷ 24000 = 0.00200

$$x = \frac{0.00200}{0.00100} = 2$$

No. of moles of $KMnO_4$ = 0.0500 x 24.0 x 10–3 = 0.00120
No. of moles of H_2O_2 = 0.00120 x 5 ÷ 2 = 0.00300

1 mole of sodium percarbonate produces y moles of H_2O_2.

$$y = \frac{0.00300}{0.00100} = 3$$

Ratio of $y : x = 3 : 2$

7 **A**

$\Delta G = \Delta H - T\Delta S$

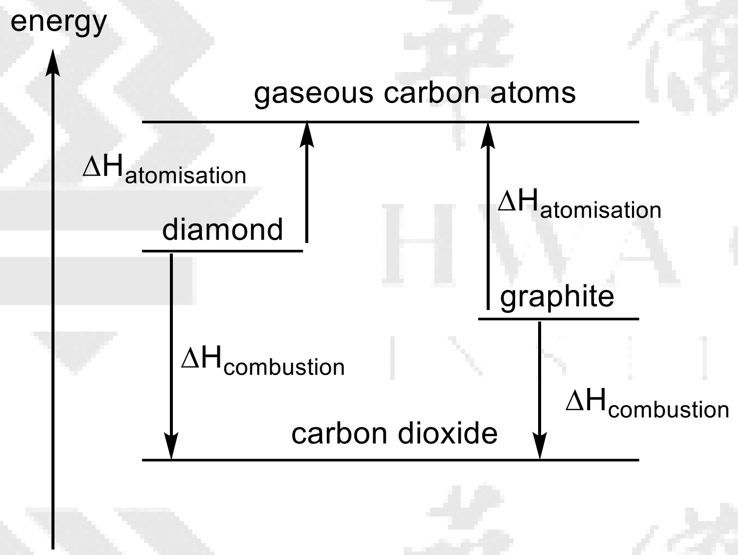
In general, ΔH & ΔS hardly changes with temperature unless there is a change in the physical state of the reactants or products. Normally, ΔG is dependent on the temperature as seen from the equation above.

For this particular reaction, ΔS is almost 0 regardless of the temperature since there are equal number of moles of gas on both sides of the arrow. Since $\Delta S \approx 0$, therefore $T\Delta S \approx 0$ and so $\Delta G \approx \Delta H$. Thus the ΔG of the reaction becomes relatively independent of temperature.

Note also that the equilibrium constant, K, is always affected by temperature unless $\Delta H = 0$.

8 **B**

The diagram below shows that the magnitude of the ΔH_{atom} for graphite is larger than that for diamond but the magnitude of ΔH_c for graphite is smaller than that for diamond.



In graphite, each C atom has a 2p orbital containing one electron that is not used in the formation of C–C bonds. The 2p orbitals can overlap with each other to form a two-dimensional delocalised π bonding system spreading throughout the whole sheet of atoms. Thus, the C–C bonds in graphite have partial double bond character. Thus the C–C bonds in graphite are stronger than those in diamond. This is also evident from the larger magnitude of ΔH_{atom} of graphite.

The rearrangement of atoms in a tetrahedral structure of carbon atoms in diamond to the trigonal planar structure of carbon atoms in graphite requires a lot of energy as many strong covalent bonds are broken. This constitutes a very high activation energy such that conversion of diamond to graphite is kinetically unfavorable despite the process having a negative ΔG.

9 **C**

The number of half-lives that it takes rock sample to decay to a ratio of 2:3 for thorium-234 to protactinium-234 is calculated as follows. Hence fraction of thorium-234 in the rock sample = $\frac{2}{2+3} = \frac{2}{5}$

$$1 \times \left(\frac{1}{2}\right)^{n} = \frac{2}{5}$$

n = 1.32 half-lives

where 1 = amount of thorium-234 at the start, and $\frac{2}{5}$ is the amount of thorium at the end of the time period of radioactive decay.

Time taken = 1.322 x 24.1 = 31.9 hr

In this question, the strategy is to recognize that more than one half-life, but less than two half-lives, have passed. So the logical answer would lie between 24.1 h and 48.2 h.

10 **B**

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In order to find the correct rate equation based on the suggested reaction mechanisms, the following steps must be taken.

The species found in the rate equation should only include the reactants and not any of the intermediates formed in the mechanism. It is helpful to write down the overall chemical equation so that the reactants are not confused with any of the intermediates.

The stoichiometry of each reactant in the slow step of a mechanism is reflected as the order of reaction of that reactant in the overall rate equation.

1. Overall equation: $2NO + 2H_2 \rightarrow N_2 + 2H_2O$
The reactants in the slow step consist of those found in the overall equation. This means that two NO molecules and one H_2 molecule are involved in the rate determining step. The rate equation should reflect this. Hence the rate equation should be rate = $k[NO]^2[H_2]$.

2. Overall equation: $2NO + O_2 \rightarrow 2NO_2$
The reactants in the slow step contain the intermediate N_2O_2 and reactant O_2. Hence the rate law based on the slow step would look like this.

rate = $k[N_2O_2][O_2]$ --- equation 1

However, N_2O_2 should not appear in the rate equation. We need to substitute $[N_2O_2]$ with the concentration of reactants that produced this intermediate into equation 1, giving rate = $k[NO_2]^2[O_2]$. Although the rate equation seems to indicate a termolecular reaction mechanism, the suggested mechanism shows otherwise.

3. Overall equation $2O_3 \rightarrow 3O_2$
In the slow step, one molecule of O_3 reacts with one atom of C*l*. Hence the overall rate equation should be rate = $k[O_3][Cl]$. The species C*l* is a homogenous catalyst since it is used up in step one and regenerated in step 2. It should appear in the rate equation as it affects the rate of reaction even if it does not appear in the overall equation.

11 **B**

	$2SO_3$ (g)	+	O_2 (g)	$\rightleftharpoons$	$2SO_3$ (g)
I / mol	0.50		1.00		–
C / mol	– 0.30		– 0.15		+ 0.30
E / mol	0.20		0.85		0.30

The equilibrium constant expression for the formation of SO_3 is written as follows:

$$K=\frac{P_{SO_3}^2}{P_{SO_2}^2 P_{O_2}}$$

$$K=\frac{\left(\frac{0.30}{0.5}\right)^2}{\left(\frac{0.20}{0.5}\right)^2\left(\frac{0.85}{0.5}\right)}=\frac{45}{34}$$

The equilibrium constant expression for the equation $SO_2(g) + \frac{1}{2}O_2(g) \rightleftharpoons SO_3(g)$ is written as follows:

$$K_c = \frac{P_{SO_3}}{P_{SO_2}\left(P_{O_2}\right)^{1/2}}$$

$$K_c = \sqrt{K} = 1.15$$

12 B

Adding a catalyst to a reversible reaction increases the rate of the forward and backward reactions equally. The equilibrium position is not affected, so the yield of the reaction is not affected by the catalysis. The catalyst merely causes equilibrium to be reached at a faster rate. The catalyst does **not** lower the activation energy of the original reaction pathway, but provides an alternative reaction pathway with a lower activation energy for both the forward and backward reactions.

13 B

See Topic 15, page 14. The graph for α vs V should be similar to that for pH vs V. As the volume of acid increases due to adding more water to dilute the acid, the pH will keep increasing while the extent of dissociation increases to almost 1 (i.e. almost complete dissociation). The pH should not exceed 7, which is the pH of water. K_a only changes with temperature.

14 A

The chemical equation for the oxidation process at the anode is given as follows:

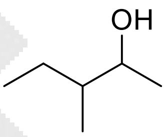
$$2Al(s) + 3H_2O(l) \rightarrow Al_2O_3(s) + 6H^+(aq) + 6e^-$$

$Q = I \times t = n_e \times F$
$n_e = It/F$ ------ (1)
$n_e : n_{Al_2O_3} = 6 : 1$ from the equation. Hence, $n_e = 6 \times n_{Al_2O_3}$ ------ (2)
Therefore, substituting (2) into (1): $n_{Al_2O_3} = It/(6F)$
mass of $Al_2O_3 = It/(6F) \times M_r(Al_2O_3)$

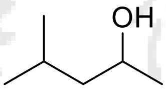
As can be seen, the mass of Al_2O_3 produced is only dependent on the current that passes through the circuit, and the time in which the current has passed through.

15 C

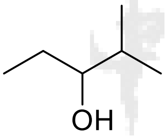
For the molecular formula $C_6H_{14}O$ to be a secondary alcohol with a branched chain, we should start with a five-carbon backbone and the –OH group in the 2nd position first, then in the 3rd position. Then explore a four-carbon backbone and place the –OH group in the 2nd position. Hence, there are a total of 4 constitutional isomers.



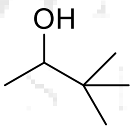
3-methylpentan-2-ol



4-methylpentan-2-ol



2-methylpentan-3-ol

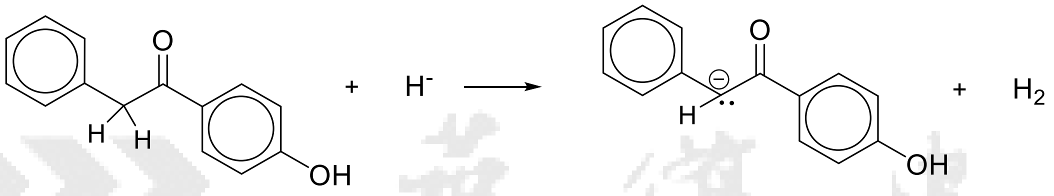


3,3-dimethylbutan-2-ol

16 **D**

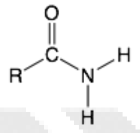
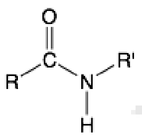
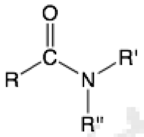
Step 1 involves the attack of the electron-deficient C atom on the C=O group of the phenylethanoic acid (the electrophile) on the benzene ring of phenol. The electrophile substitutes the H atom on the benzene ring of phenol. Hence reaction 1 is an electrophilic substitution.

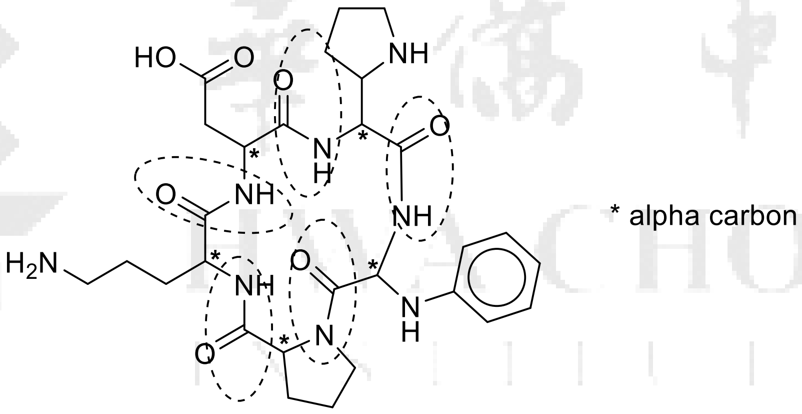
In **Step 2**, NaH provides the H^- anion, which abstracts a H^+ from the carbon next to the C=O group. This is an acid-base reaction with the ketone acting as the acid since it donates a H^+ ion, while the H^- acts as the base in receiving the H^+.



17 **A**

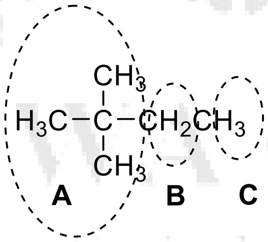
Identify the alpha-carbons in the backbone of the oligopeptide (in *). You can then easily identify the amide linkages in compound W (circled below). If you are confused as to what is an amide, refer to the table below.

Primary amides	**Substituted amides**	
		

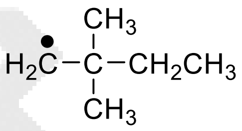


18 B

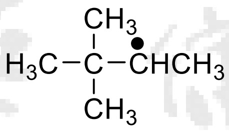
There are three different types of environments in which the hydrogens in 2,2-dimethylbutane are in, which are circled below.



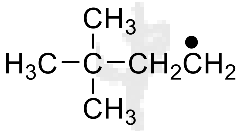
Hence, the 3 different radicals you can obtain from abstracting each type of hydrogen respectively are:


$$\overset{\bullet}{H_2C}-\underset{CH_3}{\overset{CH_3}{C}}-CH_2CH_3$$

A


$$H_3C-\underset{CH_3}{\overset{CH_3}{C}}-\overset{\bullet}{C}HCH_3$$

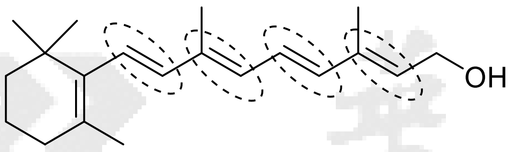
B


$$H_3C-\underset{CH_3}{\overset{CH_3}{C}}-CH_2\overset{\bullet}{C}H_2$$

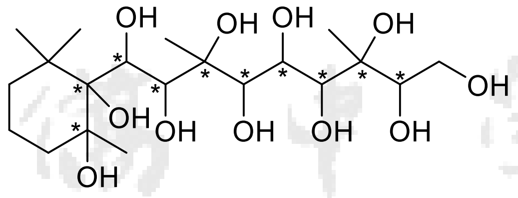
C

19 C

The C=C in retinol (except that in the cyclic ring) will exhibit cis-trans isomerism, hence 2^4. After mild oxidation to form the diol, all 5 C=C will undergo addition and give 10 chiral carbons, hence 2^{10}.



retinol



Y

20 C

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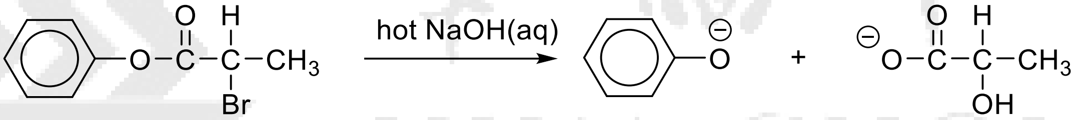
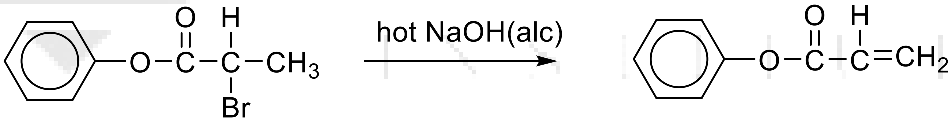
The bromoalkane undergoes nucleophilic substitution and the ester group undergoes alkaline hydrolysis with hot NaOH(aq).



(option 2)

Bromoalkane can undergo elimination with hot ethanolic NaOH.

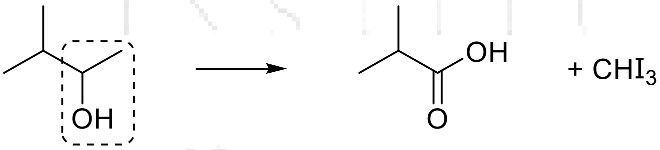


(option 3)

There are other possible products that can form from the reaction above, but they are not in the options provided. Option 1 will not be formed no matter what as no reaction would yield a benzoate ion as a possible product.

21 D

Identify the presence of $CH_3CH(OH)-$ group in the alcohol. The products formed after acidification are the carboxylic acid below and iodine.



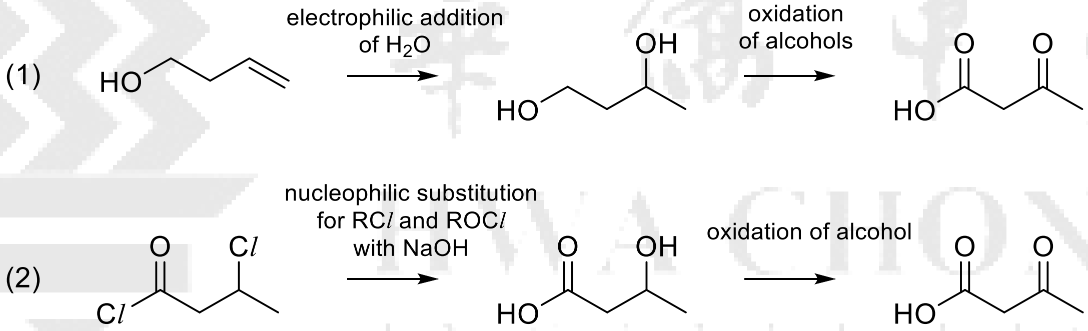
2-methylpropanoic acid

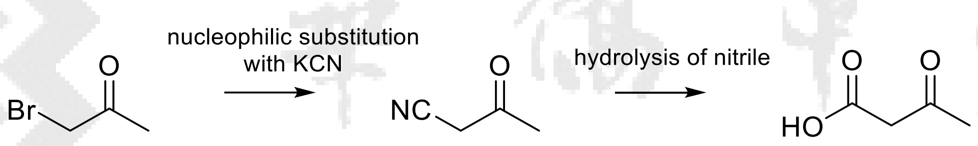
22 D

There must be 2 acidic groups in compound X which undergo acid-base reaction with NaOH(aq) since 2 mol of water is formed. Only phenols and carboxylic acids are strong enough acids to react with NaOH, but alcohols are too weak to donate a proton to NaOH.

23 D

Think of the possible transformations to form a ketone and carboxylic acid.



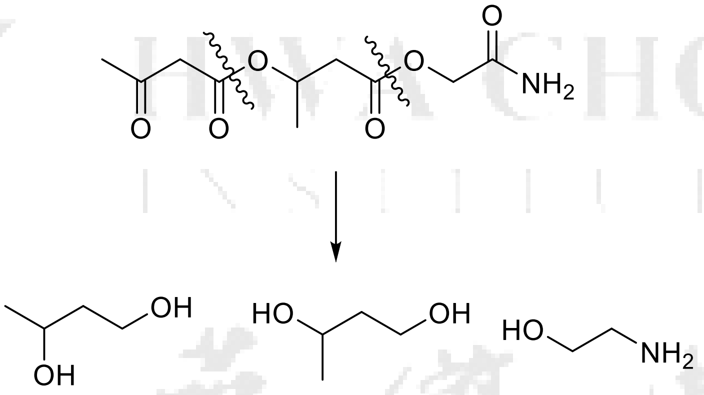
(3) 

24 **A**

Ketones and nitriles can be reduced by H_2/Ni but <u>not</u> carboxylic acids. Refer to summary of oxidising and reducing agents on pg 105 of Organic Chemistry (II) lecture notes.

25 **C**

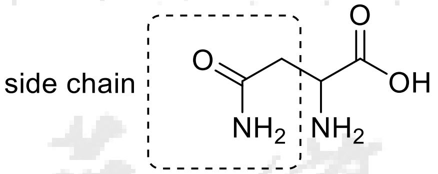
Apply the same pattern of reduction across the ester bonds to alcohols, bearing in mind that ketones are also reduced to secondary alcohols and amides are reduced to amines. Hence a total of three fragments are produced after the reaction.



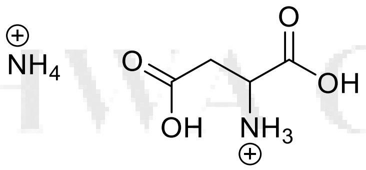
26 **B**

(1) Asparagine exists in solution as a zwitterion as it undergoes an intramolecular acid-base reaction.

(2) α-amino acids have the amino and carboxyl groups bonded directly to the same α-carbon, differing only in the side chain bonded directly to the α-carbon. The amide functional group in the side chain is neutral.



(3) The side chain of asparagine will undergo acidic hydrolysis to give the two products below. No ammonia gas is evolved.



27 A

Ionic oxides tend to be basic in nature, hence higher pH. Covalent oxides tend to be acidic oxides, hence lower pH. SiO_2 is insoluble in water, hence neutral pH. Refer to summary of properties of oxides on pg 15 of Inorganic Chemistry lecture notes.

28 C

Al_2O_3 is an inorganic ionic compound, but is insoluble in water, hence it shouldn't conduct electricity when dissolved in water. When molten, however, its ions are mobile and it will be able to conduct electricity.

$SiCl_4$ exists as simple discrete covalent molecules and cannot conduct electricity. However, it undergoes complete hydrolysis in water to give HCl(aq), which dissociates to give H^+ and Cl^- ions which are mobile charge carriers.

NaF is an inorganic ionic compound, dissolving in water to give Na^+ and F^- ions, which are mobile charge carriers.

29 D

$E^\ominus([Fe(CN)_6]^{3-}/[Fe(CN)_6]^{4-}) = +0.36V$
To oxidise $[Fe(CN)_6]^{4-}$, we need to find an oxidising reagent (which can be reduced) and whose $E^\ominus$ is more positive than +0.36V.

In your data booklet, SO_2 and NO_2 are both reducing agents as they can only be oxidized (found on right hand side of half-equations), hence both cannot be used. Cu^{2+} and I_2 are both oxidising agents, and their $E^\ominus$ values are +0.34V and +0.54V respectively, hence I_2 is the only one which can be used.

30 C

A homogeneous catalyst operates in the same phase as the reactants. Iron exhibits variable oxidation states which allows it to perform its role.

$2Fe^{2+} + S_2O_8^{2-} \rightarrow 2SO_4^{2-} + 2Fe^{3+}$ $E^\ominus_{cell} = 2.01 - 0.77 = +1.24$ V
$2Fe^{3+} + 2I^- \rightarrow 2Fe^{2+} + I_2$ $E^\ominus_{cell} = 0.77 - 0.54 = +0.23$ V