

PRACTICE PAPERS CHEMISTRY OLYMPIADS

STAGE – 2

Paper – 11 Part – B

TIME: 1HR 30MIN

MAX MARKS: 180

- Attempt all the Questions.
- All questions carry +3 for right answer and -1 for wrong answer.
- Use of Calculator is allowed.

PERIODIC TABLE OF THE ELEMENTS

1 1A																		18 8A	
1 H 1.008												13 B 10.81	14 C 12.01	15 N 14.01	16 O 16.00	17 F 19.00	2 He 4.003		
3 Li 6.941	4 Be 9.012											5 B 10.81	6 C 12.01	7 N 14.01	8 O 16.00	9 F 19.00	10 Ne 20.18		
11 Na 22.99	12 Mg 24.31	3 B 10.81	4 C 12.01	5 N 14.01	6 O 16.00	7 F 19.00	8 Ne 20.18	9 Na 22.99	10 Mg 24.31	11 Al 26.98	12 Si 28.09	13 P 30.97	14 S 32.07	15 Cl 35.45	16 Ar 39.95				
19 K 39.10	20 Ca 40.08	21 Sc 44.96	22 Ti 47.88	23 V 50.94	24 Cr 52.00	25 Mn 54.94	26 Fe 55.85	27 Co 58.93	28 Ni 58.69	29 Cu 63.55	30 Zn 65.39	31 Ga 69.72	32 Ge 72.61	33 As 74.92	34 Se 78.97	35 Br 79.90	36 Kr 83.80		
37 Rb 85.47	38 Sr 87.62	39 Y 88.91	40 Zr 91.22	41 Nb 92.91	42 Mo 95.95	43 Tc (98)	44 Ru 101.1	45 Rh 102.9	46 Pd 106.4	47 Ag 107.9	48 Cd 112.4	49 In 114.8	50 Sn 118.7	51 Sb 121.8	52 Te 127.6	53 I 126.9	54 Xe 131.3		
55 Cs 132.9	56 Ba 137.3	57 La 138.9	72 Hf 178.5	73 Ta 180.9	74 W 183.8	75 Re 186.2	76 Os 190.2	77 Ir 192.2	78 Pt 195.1	79 Au 197.0	80 Hg 200.6	81 Tl 204.4	82 Pb 207.2	83 Bi 209.0	84 Po (209)	85 At (210)	86 Rn (222)		
87 Fr (223)	88 Ra (226)	89 Ac (227)	104 Rf (261)	105 Db (262)	106 Sg (263)	107 Bh (262)	108 Hs (265)	109 Mt (266)	110 Ds (281)	111 Rg (272)	112 Cn (285)	113 Nh (286)	114 Fl (289)	115 Mc (289)	116 Lv (293)	117 Ts (294)	118 Og (294)		
58 Ce 140.1	59 Pr 140.9	60 Nd 144.2	61 Pm (145)	62 Sm 150.4	63 Eu 152.0	64 Gd 157.3	65 Tb 158.9	66 Dy 162.5	67 Ho 164.9	68 Er 167.3	69 Tm 168.9	70 Yb 173.0	71 Lu 175.0						
90 Th 232.0	91 Pa 231.0	92 U 238.0	93 Np (237)	94 Pu (244)	95 Am (243)	96 Cm (247)	97 Bk (247)	98 Cf (251)	99 Es (252)	100 Fm (257)	101 Md (258)	102 No (259)	103 Lr (262)						

Name:

Correct Questions =

Wrong Questions =

Unattempt Questions =

Marks =

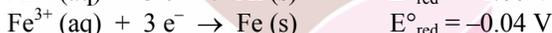
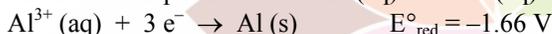
1. (11%) An organic acid containing only C, H, and O has the elemental composition by mass:

Element	% by mass
C	40.7
H	5.1

- Determine the empirical formula of this acid.
 - When 1.26 g of the acid is dissolved in 20.00 g of H₂O, the solution freezes at -1.0 °C. Determine the apparent molar mass of the compound to the proper number of significant figures. Suggest an appropriate molecular formula for the compound [$K_f = -1.86 \text{ }^\circ\text{C}\cdot\text{m}^{-1}$].
 - When a 4.00 g portion of the solution in b. is titrated with 0.226 M NaOH, 17.8 mL is required to reach a phenolphthalein end point. Calculate the number of moles of NaOH used and the apparent molar mass of the compound.
 - Use the results from b. and c. to draw a possible structural formula for this compound.
 - This compound is refluxed with excess ethanol in the presence of an acid catalyst. Write a structural formula for the organic compound formed.
 - Suppose the reaction in e. does not go to completion. Outline a method to separate the organic product from the unreacted acid.
2. (11%) Pyridine, C₅H₅N, is a weak base [$K_b = 1.78 \times 10^{-9}$].
- Calculate the [OH⁻] and pH of a 0.240 M solution of pyridine.
 - A 20.0 mL portion of 0.240 M pyridine solution is titrated with 0.120 M HCl.
 - Calculate the pH after 20.0 mL of the HCl solution has been added.
 - Calculate the pH at the equivalence point.
 - If MgCl₂ is added to a 0.240 M solution of pyridine, what is the minimum [Mg²⁺] at which Mg(OH)₂ will precipitate? [$K_{sp} = 5.6 \times 10^{-12}$]
 - For a solution with [Mg²⁺] = 0.10 M and [C₅H₅N] = 0.240M what must the [C₅H₅NH⁺] be to just prevent the precipitation of Mg(OH)₂?

3. (16%) Aluminum is a highly reducing metal.

- a. The standard reduction potentials for Al³⁺(aq) and Fe³⁺(aq) are



and the standard S^o values for these species are

species	S ^o (J/mol K)
Al (s)	28
Fe (s)	27
Al ³⁺ (aq)	-293.3
Fe ³⁺ (aq)	-313.8

- Calculate ΔG° for the reduction of Fe³⁺(aq) by Al at 25 °C.
 - Calculate ΔS° for the reduction of Fe³⁺(aq) by Al.
 - Calculate ΔH° for the reduction of Fe³⁺(aq) by Al at 25 °C.
- b. i. Construct a Born-Haber cycle for the formation of Al₂O₃ from its elements, showing each step in the process
- $$4 \text{Al}(\text{s}) + 3 \text{O}_2(\text{g}) \rightarrow 2 \text{Al}_2\text{O}_3(\text{s})$$
- ii. Use the data below to calculate the lattice enthalpy of Al₂O₃(s) in kJ/mol.

Aluminum	IE ₁ 577.6 kJ/mol	IE ₂ 1816.7 kJ/mol	IE ₃ 2744.8 kJ/mol
$\Delta H_{\text{sub}}^{\circ}(\text{Al})$	330.0 kJ/mol		
$\Delta H_{\text{f}}^{\circ}(\text{Al}_2\text{O}_3)$	-1675.7 kJ/mol		

Oxygen	EA ₁ 141.0 kJ/mol NOTE: A positive EA is exothermic.	EA ₂ -1779.6 kJ/mol
BDE (O ₂)	493.6 kJ/mol	

4. (12%) Consider the concentration cell consisting of two $\text{Cu}^{2+}(\text{aq})|\text{Cu}(\text{s})$ half-cells with different molarities. The $[\text{Cu}^{2+}]$ in the two half-cells are 2.0 M and 2.5×10^{-2} M, respectively. $[\text{Cu}^{2+}(\text{aq}) + 2\text{e}^{-} \rightarrow \text{Cu}(\text{s}) \quad E^{\circ} = 0.34 \text{ V}]$
- State the E° value for the concentration cell and explain why it has this value.
 - Calculate the cell potential, E , for the cell with the two concentrations given.
 - Identify the anode of this cell and explain your reasoning.
 - For each half-cell, predict whether the $[\text{Cu}^{2+}]$ will increase or decrease as the cell operates.
 - For the half reaction $\text{V}^{3+}(\text{aq}) + \text{e}^{-} \rightarrow \text{V}^{2+}(\text{aq})$, $E^{\circ} = -0.26 \text{ V}$.
 - Write a balanced equation for the reaction in a standard voltaic cell made with the $\text{V}^{3+}(\text{aq})/\text{V}^{2+}(\text{aq})$ and $\text{Cu}^{2+}(\text{aq})/\text{Cu}(\text{s})$ half-cells and calculate the E° value for this cell.
 - Identify the $\text{Cu}^{2+}(\text{aq})|\text{Cu}(\text{s})$ half-cell (2.0 M or 2.5×10^{-2} M) that would yield the greater E value in combination with the $\text{V}^{3+}(\text{aq})/\text{V}^{2+}(\text{aq})$ half-cell. Explain.
 - Write an expression that could be used to calculate the E value for specific $[\text{Cu}^{2+}]$, $[\text{V}^{2+}]$, and $[\text{V}^{3+}]$.
5. (12%) Write net equations for each of the reactions below. Use appropriate ionic and molecular formulas and omit formulas for all ions or molecules that do not take part in a reaction. Write structural formulas for all organic substances. You need not balance the equations.
- Sodium peroxide is added to water.
 - Barium carbonate is treated with sulfuric acid.
 - Lithium metal is heated in nitrogen gas.
 - Concentrated hydrochloric acid is added to aqueous sodium hypochlorite.
 - 2-methyl-2-propanol is mixed with cold hydrobromic acid.
 - Uranium-238 emits an alpha particle followed by a beta particle.
6. (12%) Account for the following observations about the elements in Group 14 (C - Pb) and their compounds in terms of bonding principles.
- Carbon (in the form of diamond) and silicon have the same tetrahedral structure but very pure silicon is a semiconductor while diamond is an electrical insulator.
 - Carbon and silicon both form tetrachlorides, but while CCl_4 does not react with H_2O at 25°C , SiCl_4 reacts violently with H_2O at 25°C .
 - Carbon forms compounds containing chains of carbon atoms but the tendency of the elements in the family to bond to one another in this fashion decreases with increasing atomic number.
 - Germanium, tin, and lead form stable chlorides in which they exhibit oxidation states of +2 and +4 but the +4 state decreases in stability relative to the +2 state with increasing atomic number.
7. (12%) Account for each of the following results of chemical kinetics experiments.
- When solid $\text{Pb}(\text{NO}_3)_2$ and solid KI are shaken together the mixture slowly turns yellow as PbI_2 is formed, but when aqueous solutions of the two reactants are combined a yellow precipitate of PbI_2 forms immediately.
 - For most chemical reactions the initial reaction rate is faster than the rates at later times.
 - 1 M solutions of compounds A and B decompose at identical initial rates at 25°C . At 15°C a 1 M solution of compound B shows a higher initial decomposition rate than a 1 M solution of compound A at that temperature.
 - The rate equation for the reaction: $2 \text{NO}_2 + \text{F}_2 \rightarrow 2 \text{NO}_2\text{F}$ does not include a second order dependence on NO_2 .
8. (14%) Explain the following observations about aromatic compounds.
- Benzene, C_6H_6 , does not undergo addition reactions as alkenes do despite being highly unsaturated.
 - Benzene is converted to bromobenzene on reaction with bromine. This reaction requires a Lewis acid catalyst.
 - In the presence of a Lewis acid catalyst methylbenzene reacts faster with bromine than benzene does whereas nitrobenzene reacts more slowly.
 - There are three possible isomers of dibromobenzene, $\text{C}_6\text{H}_4\text{Br}_2$, of which two are the major products formed when bromobenzene is reacted with Br_2 in the presence of a Lewis acid catalyst. Draw and name each of the three possible isomers, identify the two major products and account for this behavior.

$$\begin{array}{l}
 1. \text{ a. C } 40.7 \div 12.011 = 3.39 \div 3.39 = 1 \\
 \text{H } 5.1 \div 1.008 = 5.06 \div 3.39 = 1.5 \\
 \text{O } 54.2 \div 16.00 = 3.39 \div 3.39 = 1
 \end{array}
 \left. \begin{array}{l} \\ \\ \\ \end{array} \right\} \begin{array}{l} \times 2 = 2 \rightarrow \text{C}_2 \\ \times 2 = 3 \rightarrow \text{H}_3 \\ \times 2 = 2 \rightarrow \text{O}_2 \end{array}$$

Empirical Formula: C₂H₃O₂

$$b. \Delta T = km \quad -1.93 = -1.86m \quad m = 1.04$$

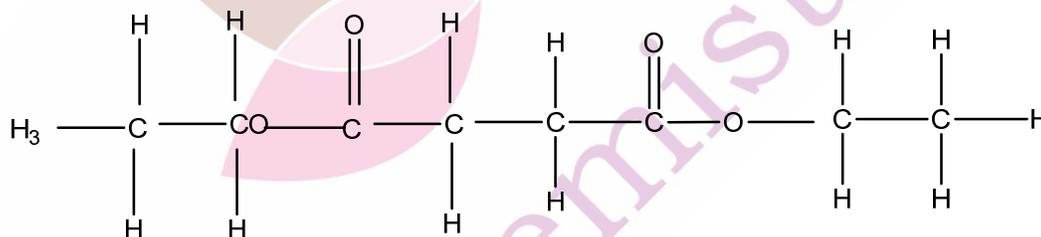
$$m = \frac{1.20 \text{g/mm}}{\text{kg}} \quad 1.04 = \frac{1.20/\text{mm}}{0.0100} \quad M = \frac{1.20}{0.0104} = 116 \quad \frac{116}{59} = 2 \text{ C}_4\text{H}_6\text{O}_4$$

Molecular Formula: C₄H₆O₄

$$\begin{array}{l}
 c. (4.00 \text{g} \div 21.26) \times (1.26) = 0.237 \text{g compound} \\
 (0.226 \text{mol/L}) \times (0.0178 \text{L}) = 0.00402 \text{ mol NaOH} \\
 (0.237 \text{g} \div 0.00402 \text{mol}) = 58.9/\text{mol} (\times 2 = 117.8/\text{mol}) \quad \therefore 2 \text{ COOH/mol}
 \end{array}$$

d. **Structural Formula:** HOOC CH₂ CH₂ COOH

e. **Structural Formula**



f. Aqueous solution of NaOH is added to mixture. Acid is converted to salt. Organic solvent (eg. C₆H₁₄ or C₂H₂Cl₂) is added to extract product while salt remains in H₂O phase.

2 a.

$$K_b = \frac{[\text{pyH}^+][\text{OH}^-]}{[\text{py}]} \quad 1.78 \times 10^{-9} = \frac{[\text{OH}^-]^2}{0.240} \quad [\text{OH}^-] = 2.07 \times 10^{-5} \quad \text{pOH} = 4.68$$

$$\text{pH} = 9.32$$

b. (i).

$$(0.240\text{M pyridine}) \times (0.0200\text{L}) = 0.0048\text{mol pyridine}$$

$$(0.120\text{M HCl}) \times (0.0200\text{L}) = 0.0024\text{mol HCl}$$

$$K_b = \frac{[\text{pyH}^+][\text{OH}^-]}{[\text{py}]} \quad K_b = [\text{OH}^-] \quad [\text{OH}^-] = 1.78 \times 10^{-9} \quad \text{pOH} = 8.75 \quad \text{pH} = 5.25$$

(ii) Equivalence point

$$(20.00\text{mL pyridine})(0.240\text{M}) + (40.00\text{mL}) (0.120\text{M HCl})$$

$$0.0800\text{M pyH}^+$$

$$K_a = \frac{K_w}{K_b} = \frac{1.0 \times 10^{-14}}{1.78 \times 10^{-9}} = \frac{[\text{H}^+][\text{py}]}{[\text{pyH}^+]} \quad 5.62 \times 10^{-6} = \frac{[\text{H}^+]^2}{0.080} \quad [\text{H}^+] = 6.70 \times 10^{-4}, \text{pH} = 3.17$$

c.

$$K_{sp} = [\text{Mg}^{2+}][\text{OH}^-]^2 \quad [\text{OH}^-] = 2.07 \times 10^{-5}$$

$$[\text{Mg}^{2+}] = \frac{5.6 \times 10^{-12}}{(2.07 \times 10^{-5})^2} = 1.3 \times 10^{-2}$$

d.

$$[\text{Mg}^{2+}] = 0.10 \quad [\text{OH}^-] = \sqrt{\frac{5.6 \times 10^{-12}}{0.10}} = 7.48 \times 10^{-6}$$

$$1.78 \times 10^{-9} = \frac{[\text{pyH}^+][7.48 \times 10^{-6}]}{0.240}$$

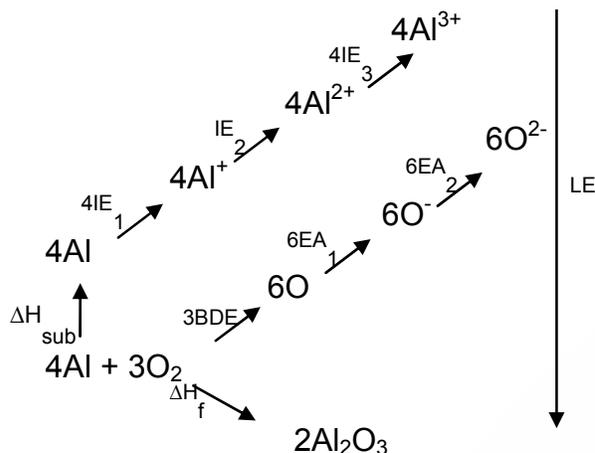
$$[\text{pyH}^+] = 5.71 \times 10^{-5}$$

3. a. (i). $E^0 = E_{\text{red}}^0 - E_{\text{ox}}^0$ $E^0 = 0.04\text{V} - (-1.66\text{V})$ $E^0 = 1.62\text{V}$
 $\Delta G^0 = -nFE^0$ $\Delta G^0 = -3 \times (96500\text{J/mol V}) \times 1.62\text{V}$ $\Delta G^0 = -468990\text{J}$

(ii). $\Delta S^0 = S_{\text{Al}^{3+}}^0 + S_{\text{Fe}}^0 - [S_{\text{Al}}^0 + S_{\text{Fe}^{3+}}^0]$
 $\Delta S^0 = -293.3 + 27 - [28 - 313.8]$
 $\Delta S^0 = -266.3 - [-285.8]$
 $\Delta S^0 = 19.5\text{J/K}$

(iii). $\Delta G^0 = \Delta H^0 - T\Delta S^0$
 $\Delta H^0 = -468990\text{J} + 298 \times (19.5\text{J/K})$
 $\Delta H^0 = -463.2\text{kJ}$

b. (i).



(ii). $2 \Delta H_f = 4 \Delta H_{\text{sub}} + 4(\text{IE}_1 + \text{IE}_2 + \text{IE}_3) + 3\text{BDE} - 6(\text{EA}_1 + \text{EA}_2) - \text{LE}$
 $2(-1675.7\text{kJ}) = 4(330.0) + 4(5139.1) + 3(493.6) - 6(141) + 6(1779.6) - \text{LE}$
 $-3351.4 = 1320 + 20556.4 + 1480.8 - 846 + 10677.6 - 2\text{LE}$
 $\text{LE} = 3351.4 + 1320 + 20556.4 + 1480.8 + 9831.6$
 $= 36540.2\text{kJ} \times 2\text{mol}$
 $= \mathbf{18270\text{kJ/mol}}$

4. a. E^0 is 0 because the 2 half-cells have the same material.
 b.

$$E = E^0 - \frac{RT}{nF} \ln \frac{[\text{Cu}^{2+}]_d}{[\text{Cu}^{2+}]_c} \quad E = 0 - \frac{0.0257}{2} \ln \frac{2.5 \times 10^{-2}}{2.0} \quad E = \frac{-0.0257}{2} \times (-4.38) = 0.056\text{V}$$

- c. The anode is the half-cell with $[\text{Cu}^{2+}] = 2.5 \times 10^{-2}$. Oxidation occurs more readily in this half-cell because the $[\text{Cu}^{2+}]$ is lower.
 d. $[\text{Cu}^{2+}]$ will increase in the half-cell with $[\text{Cu}^{2+}]_{\text{init}} = 2.5 \times 10^{-2}\text{M}$ and decrease in half-cell with $[\text{Cu}^{2+}] = 2.0\text{M}$
 e. (i). $2\text{V}^{2+} + \text{Cu}^{2+} \rightarrow 2\text{V}^{3+} + \text{Cu}$ $E^0 = 0.034\text{V} - (-0.26\text{V})$ $E^0 = 0.60\text{V}$
 (ii). Because Cu^{2+} is undergoing reduction in this cell (and Cu^{2+} is a reactant) the higher $[\text{Cu}^{2+}]_{(2.0\text{M})}$ will give the greater E value.

(iii). $E = E^0 - \frac{0.0257}{2} \ln \frac{[\text{V}^{3+}]^2}{[\text{V}^{2+}]^2 [\text{Cu}^{2+}]}$

5. a. $\text{Na}_2\text{O}_2 + \text{H}_2\text{O} \rightarrow 2\text{Na}^+ + \text{O}_2\text{H}^- + \text{OH}^-$
 b. $\text{BaCO}_3 + 2\text{H}^+ + \text{SO}_4^{2-} \rightarrow \text{BaSO}_4 + \text{H}_2\text{O} + \text{CO}_2$
 c. $6\text{Li} + \text{N}_2 \rightarrow 2\text{Li}_3\text{N}$
 d. $\text{OCl}^- + 2\text{H}^+ + \text{Cl}^- \rightarrow \text{Cl}_2 + \text{H}_2\text{O}$
 e. $\text{H}_3\text{CCOH}(\text{CH}_3)_2 + \text{H}^+ + \text{Br}^- \rightarrow \text{H}_3\text{CCBr}(\text{CH}_3)_2 + \text{H}_2\text{O}$
 f. ${}_{92}^{238}\text{U} \rightarrow {}_2^4\text{He} + {}_{90}^{234}\text{Th} \rightarrow {}_{91}^{234}\text{Pa} + {}_{-1}^0\beta$

6. a. Electrons are held in covalent bonds between C atoms in diamond. Electrons in Si (with a lower IE) can be excited to move through lattice. Valence band (fully occupied) and conduction band (empty) are widely separated in energy. In Si the

energy gap between the occupied valence band and the empty conduction band is small enough that some electrons are excited at room temperature.

b. The carbon atom in CCl_4 is protected from H_2O attack by the Cl atoms. C has no orbitals available to bond with H_2O . Si is larger, allowing H_2O access and has d orbitals available to bond with H_2O molecule in addition to having a more polar bond (Si-Cl vs. C-Cl)

c. C-C bonds are very strong because of the substantial overlap of the orbitals. Bond strength decreases down the family because the larger orbitals do not overlap as efficiently leading to weaker bonds.

d. +2 and +4 oxidation states result from the involvement of electrons from p or $s+p$ orbitals, respectively. Electrons in s orbitals become less available for bonding as atoms become larger due to penetration of s orbitals and their greater attraction to higher charged nuclei.

7. a. Lead and iodide ions in the two solids react when they come into contact with one another, which occurs only infrequently so the reaction is slow. When dissolved in H_2O the ions are free to move and react quickly when the solutions are mixed.

b. Reaction rates are typically proportional to the concentration of reactant. Because $[\text{Reactant}]$ decreases as the reaction proceeds the rate will decrease also.

c. Decomposition of A and B has different activation energies which leads to different variations with temperature. The two rate vs. temperature lines cross at 25°C giving the same rates. Since B has a higher rate at 15°C its E_a must be lower than that for compound A.

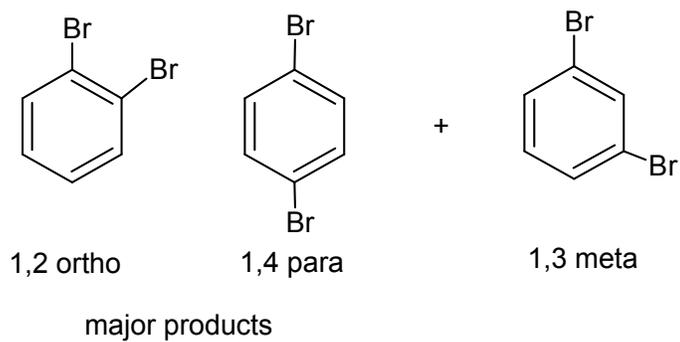
d. The ratio of atoms in the stoichiometric equation often has little to do with the order in the rate equation. The mechanism apparently has at least one NO_2 that participates in the reaction after the rate determining step.

8. a. The π electrons in C_6H_6 are delocalized so that sites do not exist where addition could occur.

b. C_6H_6 can undergo substitution reactions by an electrophilic mechanism. Interaction of Br_2 with a Lewis acid catalyst (such as FeBr_3) produces FeBr_4^- and Br^+ . The Br^+ can attack the electron-rich C_6H_6 ring, leading to substitution.

c. A CH_3 group contributes electron density to a C_6H_6 ring relative to a H atom. Higher electron density in ring leads to faster substitution. A NO_2 group withdraws electron density from a C_6H_6 ring (relative to H) producing a slower reaction.

d. Br is an ortho-para director increasing electron density more at those positions so substitution occurs there preferentially.



The Chemistry Guru

A large, stylized logo of a flower with six petals in various colors (yellow, green, pink, brown) is centered on the page. Overlaid on the page is the text 'The Chemistry Guru' in a large, purple, serif font, oriented diagonally from the bottom left to the top right.