

"Any alternative method of solution to any question that is scientifically and mathematically correct, and leads to the same answer will be accepted with full credit. Partially correct answers will gain partial credit."

For questions requiring calculations, full credit is given only if necessary steps of the calculations are written.

Problem 1

20 Marks

Lead Acid Batteries

Part A: Electrochemical processes in a lead acid cell

1.1

Reaction at Cathode: $\text{PbO}_{2(s)} + \text{SO}_4^{2-}(\text{aq}) + 4 \text{H}^+(\text{aq}) + 2\text{e}^- \rightarrow \text{PbSO}_{4(s)} + 2 \text{H}_2\text{O}(\text{l})$
 Reaction at Anode: $\text{Pb}_{(s)} + \text{SO}_4^{2-}(\text{aq}) \rightarrow \text{PbSO}_{4(s)} + 2\text{e}^-$
 Overall discharge reaction: $\text{Pb}_{(s)} + \text{PbO}_{2(s)} + 2 \text{SO}_4^{2-}(\text{aq}) + 4 \text{H}^+(\text{aq}) \rightarrow 2 \text{PbSO}_{4(s)} + 2\text{H}_2\text{O}(\text{l})$
 $E_{\text{cell}}^{\circ} = 2.05 \text{ V}$

(1.5 marks)

1.2

$\Delta H^{\circ}_{\text{rxn}} = -315.7 \text{ kJ mol}^{-1}$
 $\Delta G^{\circ}_{\text{rxn}} = -395.6 \text{ kJ mol}^{-1}$

(2.5 marks)

1.3

a) 79.9 KJ mol^{-1}

(1 mark)

b) Fraction obtained from the surrounding = 0.2 (or 1/5 or 20%)

(1 mark)

1.4

$$E = E^{\circ} - \frac{RT}{2F} \ln \frac{a_{\text{H}_2\text{O}}^2}{\left(a_{\text{SO}_4^{2-}}\right)^2 \left(a_{\text{H}^+}\right)^2} = E^{\circ} - \frac{RT}{F} \ln \frac{a_{\text{H}_2\text{O}}}{\left(a_{\text{SO}_4^{2-}}\right)^2 \left(a_{\text{H}^+}\right)^2}$$

(0.5 mark)

1.5

Drop in EMF: 0.16 V

(1.5 marks)

1.6

i, ii

(2 marks)

- | | Correct | Incorrect | | Correct | Incorrect |
|-----|---------|-------------------------------------|----|-------------------------------------|-------------|
| 1.7 | a) | <input checked="" type="checkbox"/> | d) | <input checked="" type="checkbox"/> | |
| | b) | <input checked="" type="checkbox"/> | e) | <input checked="" type="checkbox"/> | |
| | c) | <input checked="" type="checkbox"/> | | | (2.5 marks) |

- 1.8
- Cathodic: $\text{PbO}_{2(s)} + 4 \text{H}^+_{(aq)} + 2\text{e}^- \rightarrow \text{Pb}^{2+}_{(aq)} + 2 \text{H}_2\text{O}_{(l)}$

Anodic: $\text{Pb}_{(s)} \rightarrow \text{Pb}^{2+}_{(aq)} + 2\text{e}^-$

Overall Discharge reaction: $\text{Pb}_{(s)} + \text{PbO}_{2(s)} + 4 \text{H}^+_{(aq)} \rightarrow 2 \text{Pb}^{2+}_{(aq)} + 2 \text{H}_2\text{O}_{(l)}$

Potential difference (open circuit voltage or EMF) = E°_{cell} = 1.59 V
- (1.5 marks)

- 1.9
- | | True | False |
|----|-------------------------------------|-------------------------------------|
| a. | <input type="checkbox"/> | <input checked="" type="checkbox"/> |
| b. | <input type="checkbox"/> | <input checked="" type="checkbox"/> |
| c. | <input checked="" type="checkbox"/> | <input type="checkbox"/> |
- (1.5 marks)

- 1.10
- PbO₂ plate: $2 \text{PbO}_{2(s)} + 4 \text{CH}_3\text{SO}_3\text{H}_{(aq)} \rightarrow 2 \text{Pb}(\text{CH}_3\text{SO}_3)_2_{(aq)} + \text{O}_{2(g)} + 2\text{H}_2\text{O}_{(l)}$

(and/or: $\text{Pb}_{(s)} + \text{PbO}_{2(s)} + 4 \text{CH}_3\text{SO}_3\text{H}_{(aq)} \rightarrow 2 \text{Pb}(\text{CH}_3\text{SO}_3)_2_{(aq)} + 2\text{H}_2\text{O}_{(l)}$)

Pb plate: $\text{Pb} + 2 \text{CH}_3\text{SO}_3\text{H}_{(aq)} \rightarrow \text{Pb}(\text{CH}_3\text{SO}_3)_2_{(aq)} + \text{H}_{2(g)}$

$\text{PbSO}_4 + 2 \text{CH}_3\text{SO}_3\text{H}_{(aq)} \rightarrow \text{Pb}(\text{CH}_3\text{SO}_3)_2_{(aq)} + \text{H}_2\text{SO}_{4(l)}$ (considered for partial credit)
- (2 marks)

- 1.11
- | | |
|--|-----------------------------|
| A: $(\text{NH}_4)_2\text{CO}_3$ or $(\text{NH}_4)\text{HCO}_3$ | B: PbCO_3 |
| or | |
| A: $(\text{NH}_4)_2\text{C}_2\text{O}_4$ | B: PbC_2O_4 |
- (1 mark)

- 1.12
- MW of C = 60 g.mol⁻¹

C: CH₃COOH
- (1 mark)

- 1.13
- X: PbI₂
- (0.5 mark)

Problem 2

25 marks

When Rain meets the Soil

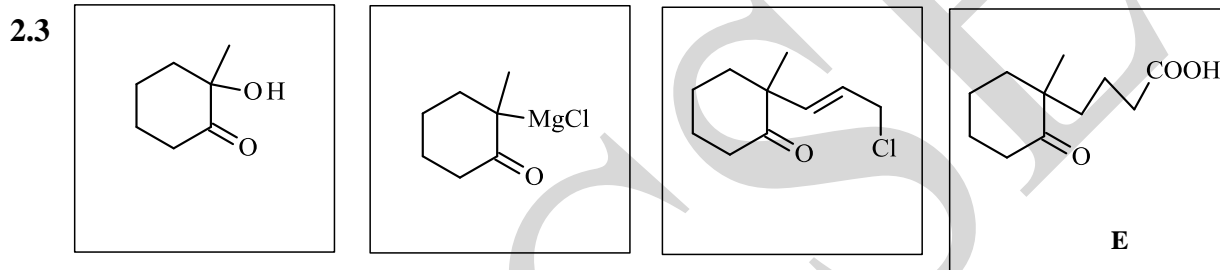
Part I: The fragrance of soil

2.1 Amount of C = 0.359 g
Percentage of C = 79%

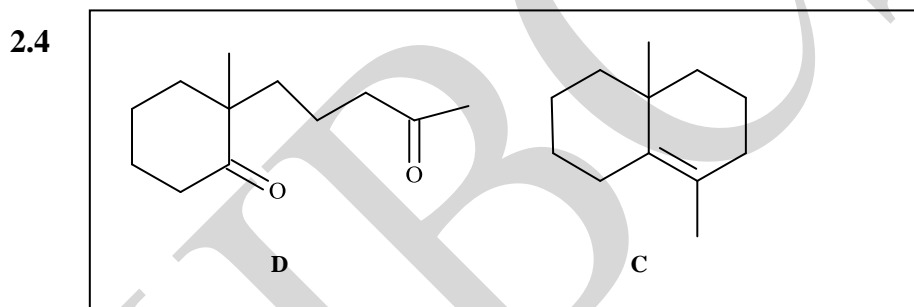
(1 mark)

2.2 Empirical formula: $C_{12}H_{22}O$

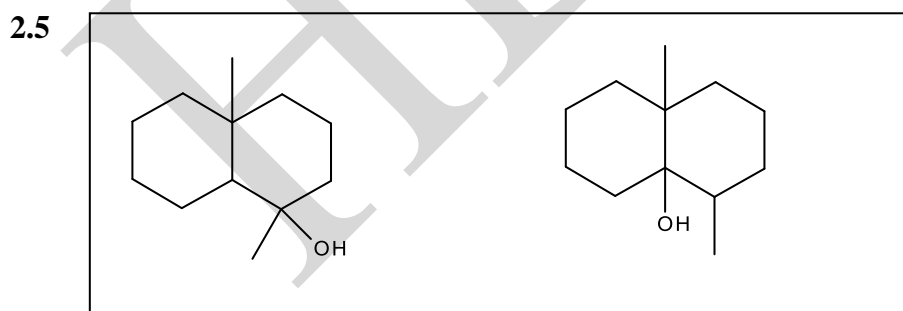
(3 marks)



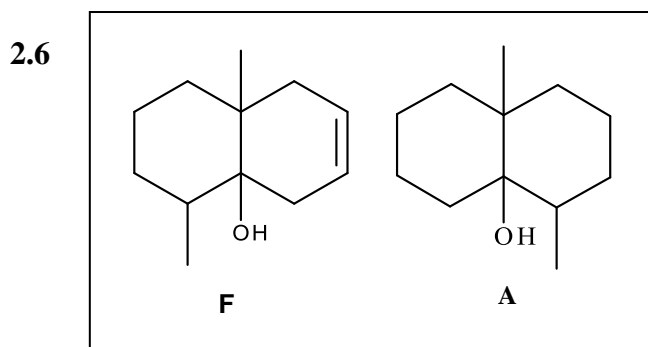
(3 marks)



(2 marks)

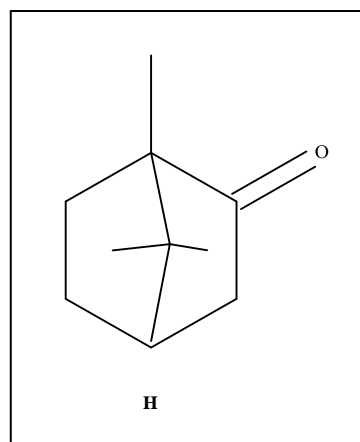
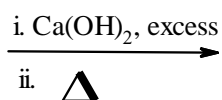
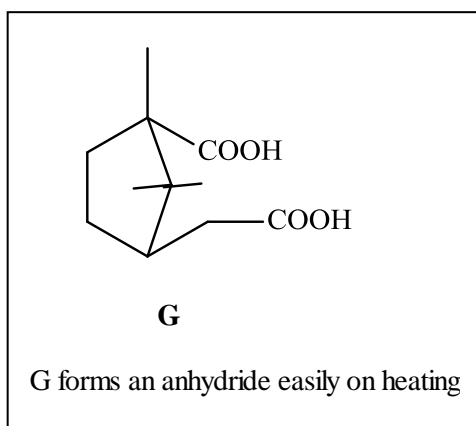


(1 mark)



(2 marks)

2.7



(1.5 marks)

2.8 a) $\text{pH} = 9.5-6.5 ; 5.6-2.8$

(1 mark)

b) 63.3 mL of 0.03 M H_2SO_4

(1 mark)

c) i) X

(0.5 mark)

2.9 $\text{pH} = 9.86$

(3 marks)

2.10 Vol of 0.03 M $\text{H}_2\text{SO}_4 = 0.45 \text{ mL}$

(3.5 marks)

2.11 b. X

(0.5 mark)

2.12 b. X

(0.5 mark)

2.13 i) Na_2CO_3

ii) Na_2CO_3

iii) CaCO_3

(1.5 marks)

Problem 3

21 Marks

Hydrogen Bonding and Water of Crystallization

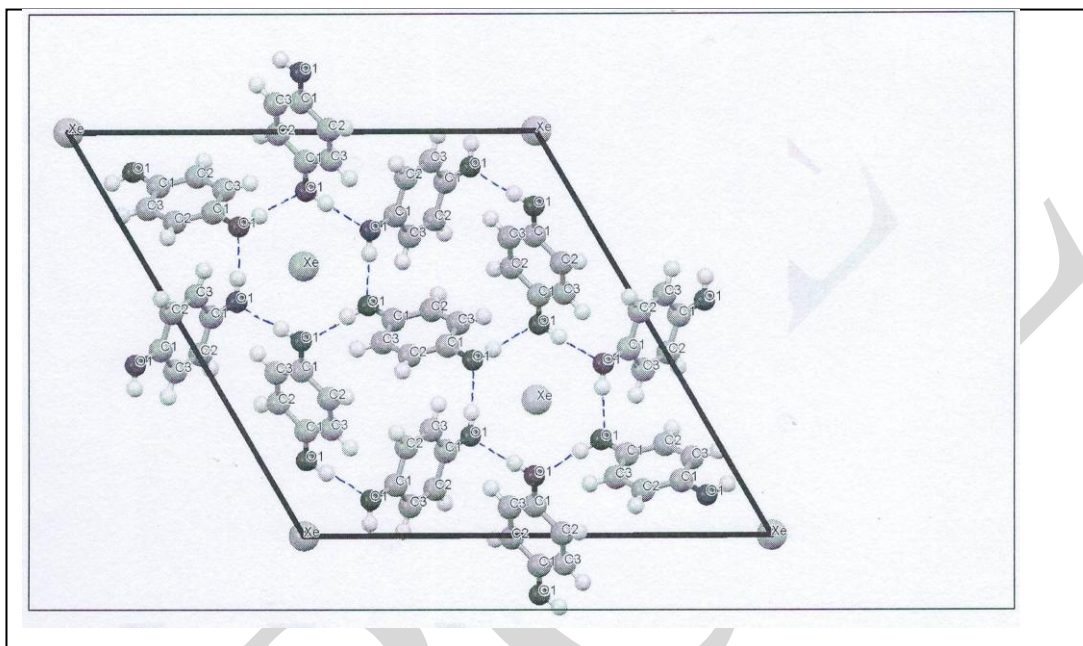
Part 1

3.1 (a)

(c)

(1.5 marks)

3.2



(1 mark)

3.3

In unit cell
p - quinol molecules = 9
 Xe atoms = 3 atoms

(3 marks)

3.4

Density = 1,778 kg m⁻³

(3 marks)

3.5

Volume = 93.1 cm³

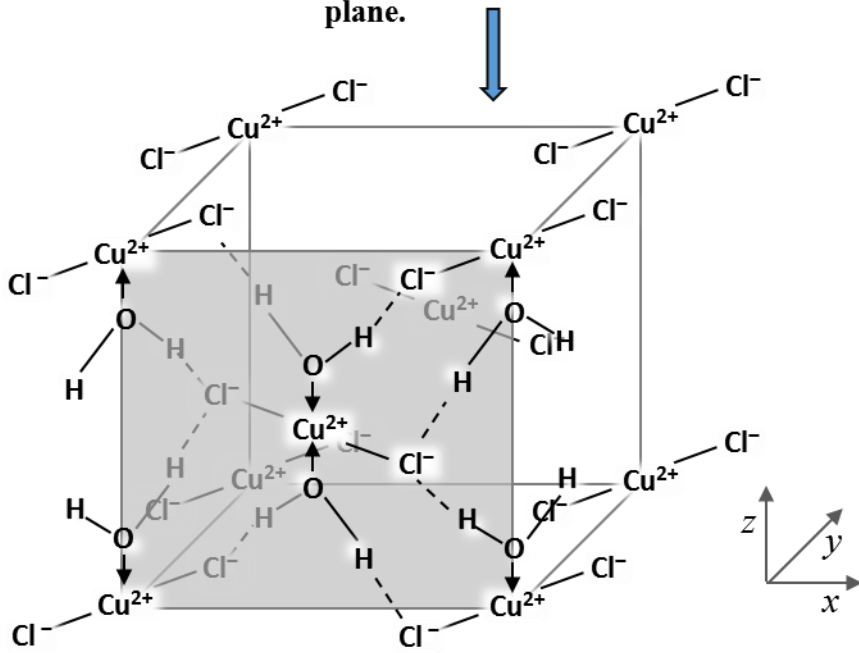
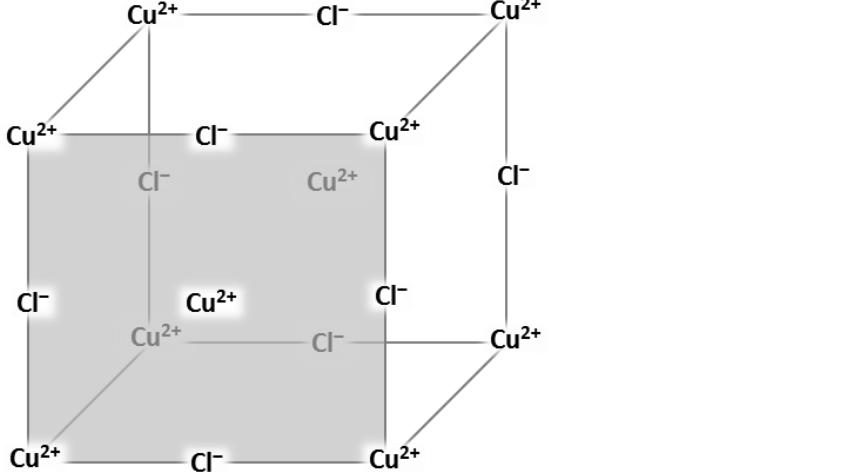
(2.5 marks)

3.6

(i)

(1 mark)

3.7

| Framework | Reason/s for impossible framework wherever applicable |
|---|---|
| <p style="text-align: center;">Similarly, there would be H₂O molecules in the back plane.</p> <p style="text-align: center;">↓</p>  | |
|  | <p>III</p> |

| | |
|--|----|
| | I |
| | II |

(6 marks)

3.8

$$\Delta H_{\text{sol}} = 37.75 \text{ kJ/mol}$$

(2 marks)

3.9

21.37 kg anhydrous CuCl_2

(1 mark)

Problem 4

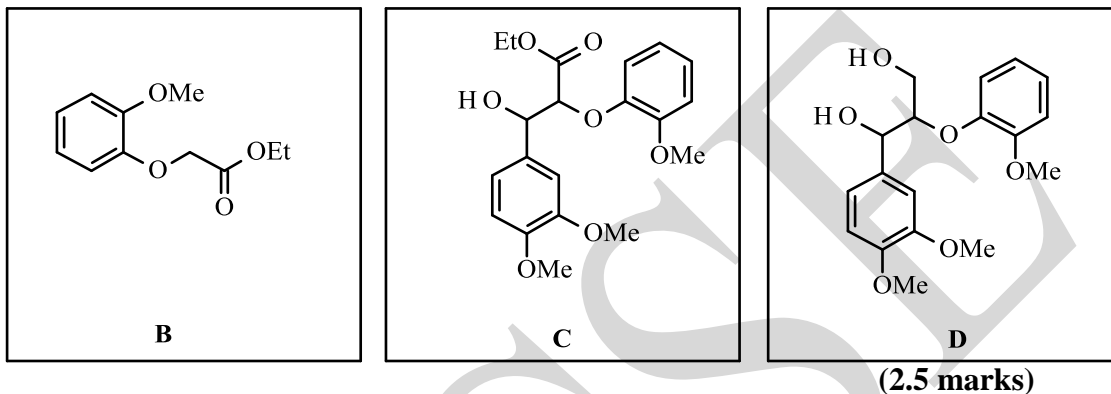
19 Marks

Lignin

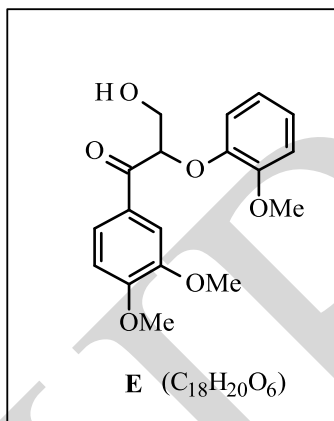
4.1 In the above structure of lignin, identify the functional groups present. (Mark X against the correct option/s)

- a) b) c) f) (1 mark)

4.2

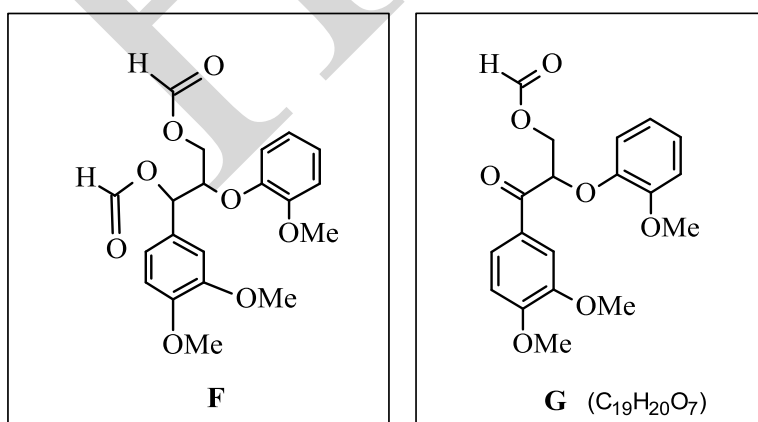


4.3



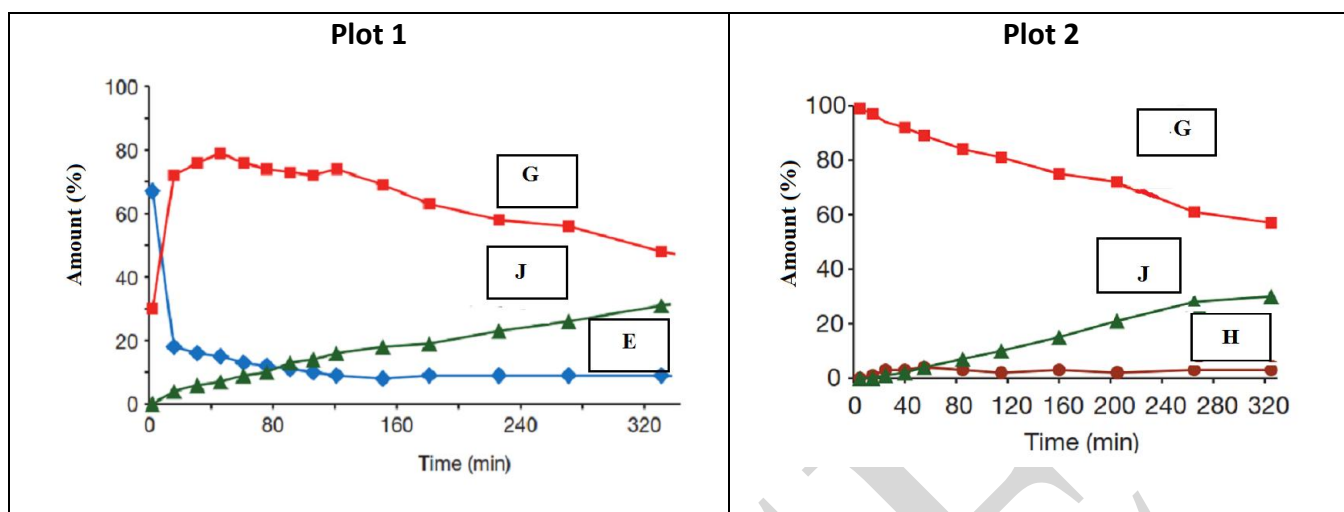
(1 mark)

4.4



(1 mark)

4.5



(2 marks)

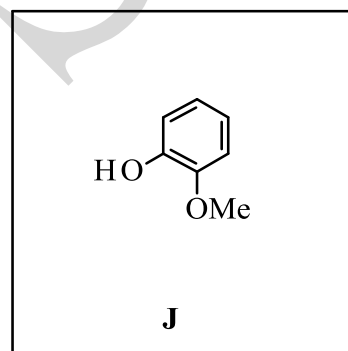
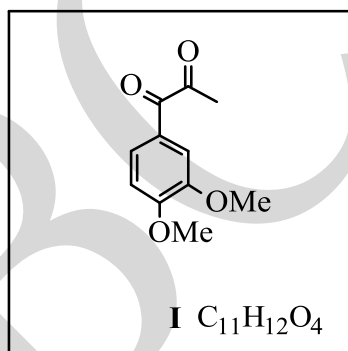
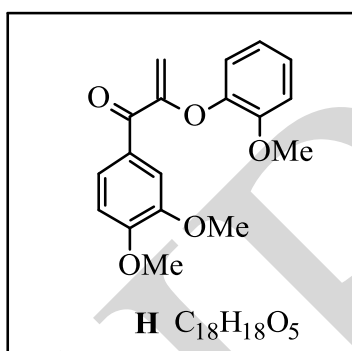
4.6 iv) (if (i) is marked along with (iv) then given full credit)

(1 mark)

4.7 b) c)

(1.5 marks)

4.8

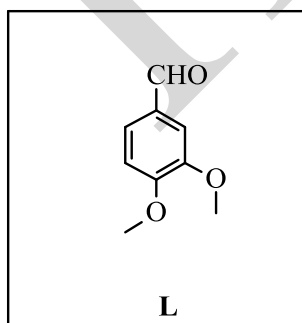


(3 marks)

4.9 b) c)

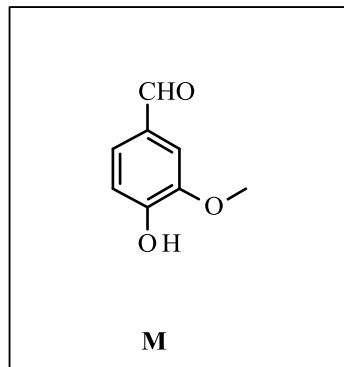
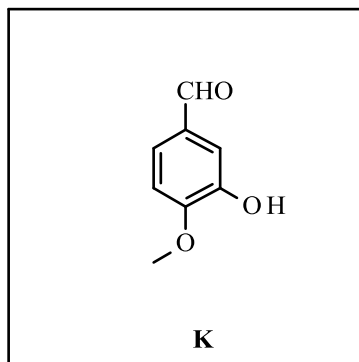
(2 marks)

4.10



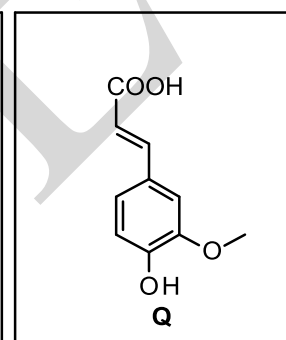
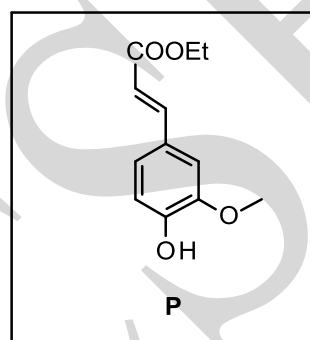
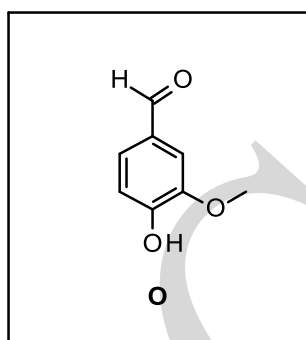
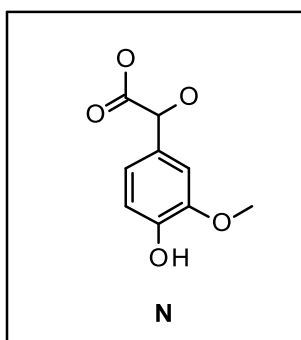
(0.5 mark)

4.11



(1 mark)

4.12



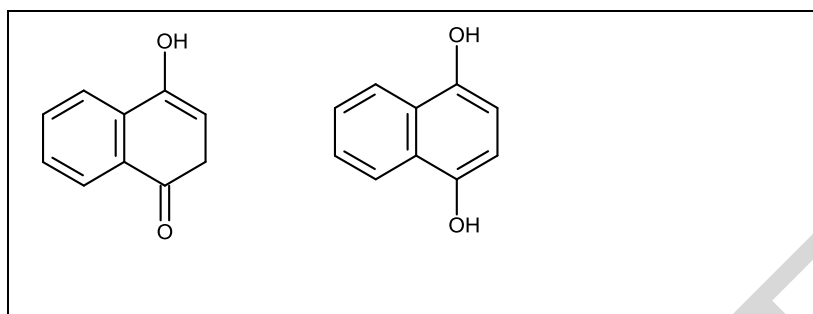
(2.5 marks)

Problem 5

22 marks

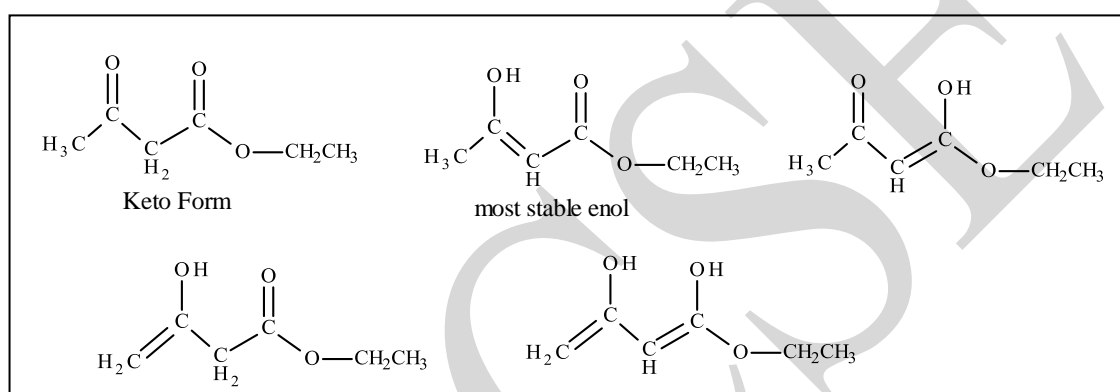
Keto-Enol Tautomerism: Kinetics and Thermodynamics

5.1



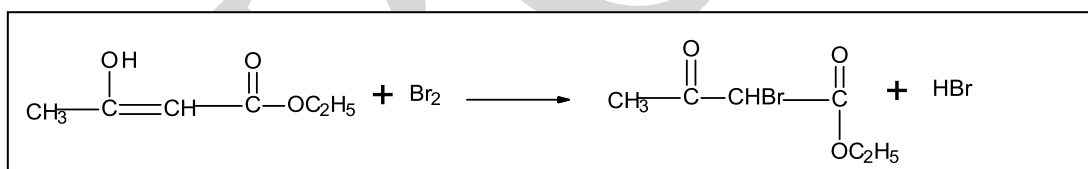
(1 mark)

5.2



(2.5 marks)

5.3



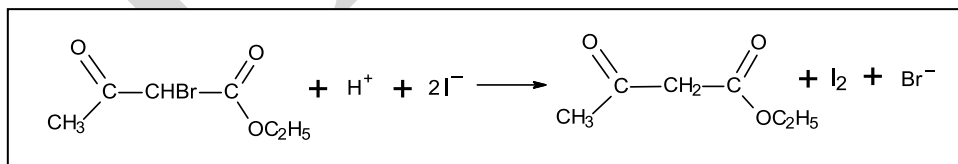
(1 mark)

5.4

 ii) X

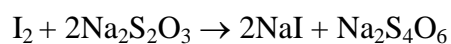
(1 mark)

5.5

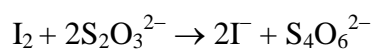


(1 mark)

5.6



(0.5 mark)



5.7

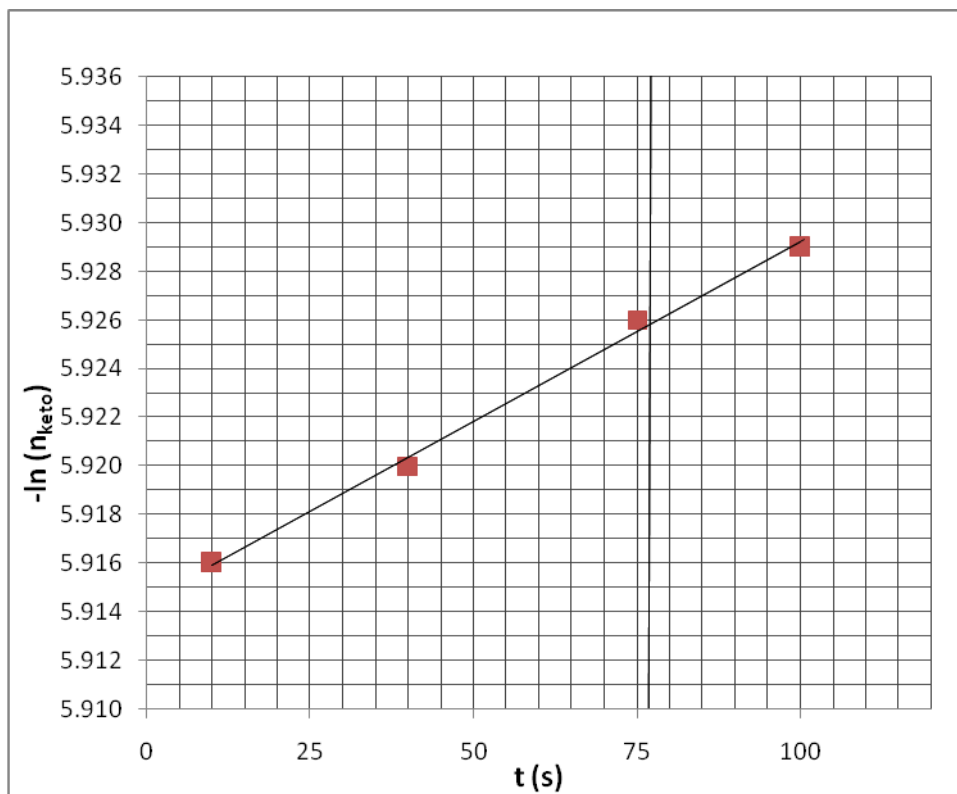
Flask A: Moles of ketone = 2.695×10^{-3} mol

Flasks B: Moles of ketone = 2.683×10^{-3} mol

Flasks C: Moles of ketone = 2.669×10^{-3} mol

(3 marks)

5.8



a. Order = 1

b. Rate Constant = $1.480 \times 10^{-4} \text{ s}^{-1}$

c. $K_{\text{eq}} = 0.068093$

(4 marks)

5.9

$$\Delta S^{\circ} = -0.0348 \text{ kJ mol}^{-1} \text{ K}^{-1}$$

$$\Delta H^{\circ} = -3.69 \text{ kJ mol}^{-1}$$

(3 marks)

5.10

(ii) **X**

(0.5 mark)

5.11

$$t = 1.08 \text{ hr or } 3907 \text{ s}$$

(4.5 marks)