



**GWANDA STATE UNIVERSITY**  
**FACULTY OF ENGINEERING AND THE ENVIRONMENT**  
**DEPARTMENT OF METALLURGICAL ENGINEERING**  
**EMG 3201 INTRODUCTION TO HYDROMETALLURGY**  
**Part III Second Semester Final Examination Paper**  
**April 2025**

This examination paper consists of 7 printed pages

**Time Allowed:** 3 hours

**Total Marks:** 100

**Examiner's Name:** Mr P. Chamboko

**INSTRUCTIONS**

1. Answer any four questions.
2. Each question carries 25 marks
3. Use of calculators is permissible

**Additional requirements**

Graph paper (on request)

**MARK ALLOCATION**

Questions 1 to 5	25 Marks
Part Marks	As shown in each part question
Total Attainable	100 Marks

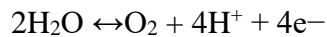
**NB: DO NOT TURN OVER THE QUESTION PAPER OR COMMENCE WRITING UNTIL INSTRUCTED TO DO SO**

**Question 1:**

- (a) Use the (micro)structure of an activated carbon flake to explain the mechanisms involved in the uptake of gold from its cyanide solution. A drawing of the (micro)structure would assist in the explanation. **[5 marks]**
- (b) You are given the following electrochemical reactions and data for the Au-H<sub>2</sub>O system at standard conditions at 25°C (298K).

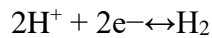
**Water Stability Limits:**

Upper limit (oxygen evolution):



$$E = 1.23 - 0.0591 \text{ pH}$$

Lower limit (hydrogen evolution):



$$E = 0 - 0.0591 \text{ pH}$$

Consider each equilibrium equation separately: When considering leaching, an activity of 10<sup>-3</sup> mol.kg<sup>-1</sup> for all metal ionic species may be considered to represent a significant concentration of the species in aqueous solution.

- i. Use the information above to construct the Eh-pH diagram of the Au-H<sub>2</sub>O system and label the stability regions for Au<sup>0</sup>, Au<sup>+</sup>, Au<sup>3+</sup>, and Au(OH)<sub>3</sub>. **[10 marks]**

- ii. Using the Eh-pH diagram that you constructed in (i), discuss the thermodynamic requirements for the electrowinning of the Au. In your answer, clearly indicate the expected reactions and the minimum potential required to plate the Au [5 marks]

(c) A gold ore particle (radius 150  $\mu\text{m}$ ) undergoes cyanide leaching with:

- Surface reaction rate constant ( $k$ ) =  $8 \times 10^{-8}$  m/s
- Diffusion coefficient ( $D_{\text{eff}}$ ) =  $3 \times 10^{-11}$  m<sup>2</sup>/s
- Bulk cyanide concentration = 0.05 M

Calculate:

- (i) The time needed for 80% extraction under mixed control. [3 marks]
- (ii) The dominant control mechanism at the end of the leaching process. [2 marks]

$$\text{Equation: } t = \frac{r_o}{k} [1 - (1 - X)^{\frac{1}{3}}] + \frac{r_o^2}{6D_{\text{eff}}} [1 - 3(1 - X)^{\frac{2}{3}} + 2(1 - X)]$$

### Question 2:

- (a) Inorganic acids such as hydrochloric acid are commonly used as lixivants in the leaching process. The concentration of the acid lixiviant solution and residential time are parameters that need to be optimized by carrying out leaching experiments with different concentrations at different residential times.

Show how you would prepare a 1.5 M HCl solution in 1000 ml, given that the HCl concentration you are using is 32 %. Density is 1.16 g/cm<sup>-3</sup>, and molecular weight is 36.46 g/mol. [5 marks]

- (b) The table below shows the leaching data for Co<sup>2+</sup> in different concentrations of hydrochloric acid as a function of the residential time. The leaching data is given as a percentage of Co<sup>2+</sup> recovery. The feed to the leaching vessel was 70 ppm Co.

Table 1: Leaching data for  $\text{Co}^{2+}$  in different concentrations of hydrochloric acid as a function of the residential time

<b>Time (minutes)</b>	<b>0.5 M HCl <math>\text{Co}^{2+}</math> recovery</b>	<b>1.0 M HCl <math>\text{Co}^{2+}</math> recovery</b>	<b>1.5 M HCl <math>\text{Co}^{2+}</math> recovery</b>
30	10	15	20
60	25	35	45
90	50	60	70
120	65	78	83
150	75	80	88
180	80	86	95
210	83	90	99
240	86	95	105

Draw the curve expressing:

- (i) the concentration of  $\text{Co}^{2+}$  in the leachate as a function of time and **[5 marks]**
- (ii) as a function of the concentration of the lixiviant **[5 marks]**
- (Hint: show tabulated and related values). **[5 marks]**
- (iii) Identify the plot of  $\text{Co}^{2+}$  concentration versus time and give the optimum time to stop the leaching process. **[2 marks]**
- (iv) Explain the effect of the concentration of the lixiviant on the recovery of cobalt. **[3 marks]**

**Question 3:**

- (a) Explain the chemical reactions involved in the formation of acid mine drainage (AMD). Discuss the long-term environmental impacts of AMD and propose sustainable mitigation measures. **[5 marks]**

- (b) A mine site has an AMD problem with a pH of 3.5 and a high concentration of dissolved iron ( $\text{Fe}^{2+}$ ). Design a treatment process to neutralize the AMD and remove the iron. Include the chemical reactions involved and justify your choice of reagents. **[5 marks]**
- (c) Calculate the mass of Zn deposited onto an inert lead cathode in an electrolytic extraction of zinc where the electrolytic cell is receiving a current of 20 Amps for 6 hours. The atomic weight of Zn is 65.409. **[5 marks]**
- (d) Calculate the percentage of copper precipitated from a solution containing originally 0.5 copper/ $\text{dm}^3$ , pH is 6.05, and  $K_{\text{sp}}$  for the reaction;  

$$\text{Cu}(\text{OH})_2(\text{s}) = \text{Cu}^{2+}(\text{aq}) + 2\text{OH}^{-}(\text{aq}) \text{ is } 2.20 \times 10^{-20}$$
 **[5 marks]**
- (e) A pregnant solution from the leaching of an oxidized Cu-Co ore contains 3% Co, 35% Cu, and 30% Fe, with the balance made out of the commonly found siliceous gangue components. Suggest and design hydrometallurgical recovery routes for Co and Cu where appropriate solvent extraction reagents are used. [Hint: a flowsheet may be useful]. **[5 marks]**

**Question 4:**

- (a) During the metal extraction through electrowinning, hydrogen may evolve from the electrodes. This would impede the effectiveness of the metal extraction process. Explain how to minimize or prevent the above hydrogen evolution from happening. **[5 marks]**
- (b) Metal activity in the electrolyte decreases as time evolves during the electrowinning process. Using the Nernst equation in the electrowinning of nickel explains the need to replenish the electrolytic bath with the feed of the same initial concentration for a fixed operating external voltage. **[5 marks]**
- (c) With the aid of standard reduction potentials, explain why for the electrolytic extraction of Zn from its hydrometallurgical solution, one has first to remove the Fe present. **[4 marks]**

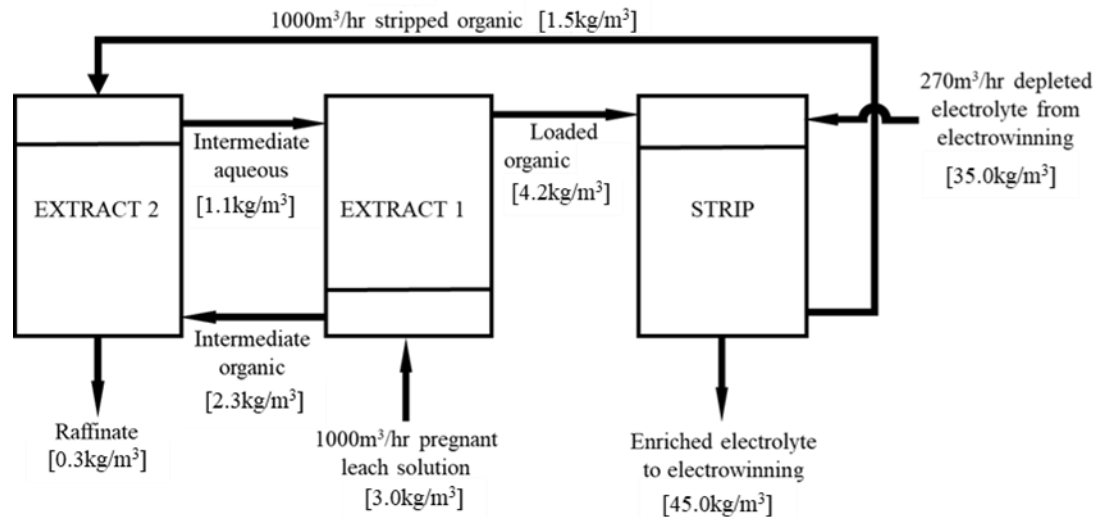
(d) A hydrometallurgical solution contains Cu, Ni, and Co in quantities enough to be recovered in an economical electrolytic route. Suggest a specific way for the extraction of each of the individual metals. Justify your opinion. **[8 marks]**

(e) During the electrowinning of base metals, the Nernst equation is used to set and fix the potential of the electrolytic cell for an optimized metal recovery. As the process proceeds, bleeding of the electrolyte is required.

Explain the electrolyte bleeding process. **[3 marks]**

**Question 5:**

(a) Figure 1 shows the plan view of a series-solvent-extraction circuit commonly used for Cu purification. The numbers in square brackets represent Cu concentrations in  $\text{kg/m}^3$ .



It is given that the solvent used (LX98N) can extract 0.25kg of Cu per  $\text{m}^3$  of organic phase per volume % of LX98N in the organic phase.

- (i) Using mass balance, calculate the strength (in %) of LX98N required to extract a specified amount of Cu. **[2 marks]**
- (ii) Calculate the Cu extraction rate in kg/hr. **[2 marks]**
- (iii) Calculate the Cu extraction efficiency of the circuit. **[3 marks]**

- (iv) Given that the electrowinning plant must plate 2,700 kg of Cu per hour, calculate the flow rate of the electrolyte in m<sup>3</sup>/hr. **[5 marks]**
- (b) As a senior metallurgist at a gold plant using the cyanidation process, you have recently seen a worrying trend in the daily recordings of process parameters. The gold assays of the tailings have been increasing lately, and the plant is losing a lot of gold. It is estimated that \$ 40,000 equivalent of gold is being lost. The directors have summoned you to solve this problem urgently. You checked the operating parameters, i.e., cyanide concentration, residence time, and pH, and you did not identify any anomalies.
- (i) A fellow metallurgist at another plant has suggested that you should increase the cyanide concentration. Give a detailed explanation of how you would respond to this suggestion to see if or not it is a solution. **[6 marks]**
- (ii) Detail other important parameters that you think should be checked and explain why you think they are important. **[4 marks]**
- (iii) Your investigations reveal that the ore characterization has varied from the usual ore the plant receives. What changes in the ore could have led to the problem that the plant is experiencing? **[3 marks]**

**END OF EXAMINATION**