



SCHOOL OF SCIENCE AND TECHNOLOGY

Semester 2, 2025

FINAL EXAMINATION PAPER

CHE212: ORGANIC AND ANALYTICAL CHEMISTRY

Important Instructions to Students:

1. There are 9 pages. Read the questions and instructions carefully and answer the questions.
2. You are allowed an **extra 10 minutes of reading time** (during this time, you are not allowed to write with pen) and **180 minutes (3 Hours) to complete this paper**.
3. Silent, non-programmable calculators are allowed, but not supplied.
4. Write all your answers in the answer booklet provided. If you need extra sheets, please ask the supervisor. Write your name, course code and student identification number in the answer booklet and in the attendance sheet.
5. This paper contains three (3) sections A, B, and C. All questions are compulsory to answer.
6. Write all your answers legibly. Ensure that all question numbers are properly written before the answer. The marker has the right to award zero for answers that are not legible.
7. This is a **Closed Book Examination**. The University views plagiarism, cheating and dishonest practice as serious offences and if found, offenders are penalized.

Examination Paper Content (Format):

<u>Section</u>	<u>Question</u>	<u>Content</u>	<u>Marks</u>	<u>Suggested Time</u>
A	1-20	Multiple Choice	20	20 minutes
B	1-5	Short Answer Questions	50	120 minutes
C	1-3	Long Answer Questions	30	40 minutes
		TOTAL	100	180 Minutes

There are 20 multiple choice questions. All are compulsory. Write the letter of the best answer in your answer booklet.

1. According to Baeyer's strain theory, the instability of small cycloalkanes is mainly due to:
 - A. Torsional strain only
 - B. Angle strain due to deviation from ideal bond angles
 - C. Resonance effects
 - D. Steric hindrance
2. Cyclopropane exhibits unusual reactivity because:
 - A. It is aromatic
 - B. Its C–C bonds are bent ("banana bonds") and have increased p-character
 - C. It has no strain
 - D. It has conjugated double bonds
3. In a monosubstituted cyclohexane, the substituent is most stable when it is in the:
 - A. Axial position
 - B. Equatorial position
 - C. Planar position
 - D. Bridgehead position
4. The 1,3-diaxial interaction in cyclohexane arises between:
 - A. Two equatorial hydrogens on adjacent carbons
 - B. An axial substituent on C1 and axial hydrogens on C3 and C5
 - C. Substituents on opposite sides of the ring
 - D. Axial substituent and equatorial substituent on the same carbon
5. Gauche interaction in butane is:
 - A. Steric strain when methyl groups are 60° apart
 - B. Torsional strain between eclipsed hydrogens
 - C. The most stable conformation
 - D. Hydrogen bonding interaction
6. In the chair conformation of cyclohexane, ring inversion (flip):
 - A. Converts all axial bonds to equatorial and vice versa
 - B. Leaves all substituents in the same orientation
 - C. Is impossible at room temperature
 - D. Destroys the ring structure
7. The Friedel–Crafts alkylation of benzene is often limited by:
 - A. Overalkylation and carbocation rearrangements
 - B. Lack of reactivity of benzene
 - C. Formation of only meta products
 - D. Steric hindrance from catalyst

8. Which of the following is a strong deactivator and meta-directing group in Electrophilic Aromatic Substitution (EAS)?
- A. $-\text{CH}_3$
 - B. $-\text{OH}$
 - C. $-\text{NO}_2$
 - D. $-\text{OCH}_3$
9. Huckel's rule for aromaticity requires that a planar cyclic molecule must have:
- A. $4n$ π electrons
 - B. $4n+2$ π electrons
 - C. Any even number of π electrons
 - D. $2n$ π electrons
10. Cyclooctatetraene (COT) is classified as:
- A. Aromatic and planar
 - B. Antiaromatic and planar
 - C. Nonaromatic and tub-shaped (nonplanar)
 - D. Aromatic only when ionized
11. Cyclopentadienyl anion (C_5H_5^-) is aromatic because it has:
- A. 4 π electrons
 - B. 6 π electrons and a planar conjugated system
 - C. 8 π electrons
 - D. No delocalization
12. The tropylium ion (C_7H_7^+) is aromatic because it has:
- A. 4 π electrons
 - B. 6 π electrons delocalized over 7 atoms
 - C. 8 π electrons
 - D. 10 π electrons
13. In Electrophilic Aromatic Substitution (EAS), the rate-determining step is:
- A. Deprotonation to restore aromaticity
 - B. Formation of the σ -complex (arenium ion)
 - C. Electrophile generation
 - D. Protonation of the aromatic ring
14. The Friedel-Crafts reaction cannot occur on nitrobenzene because:
- A. The nitro group deactivates the ring and binds to Lewis acid catalyst
 - B. Nitrobenzene is too reactive
 - C. The nitro group is ortho/para directing
 - D. Nitro group promotes polymerization

15. In naphthalene, electrophilic substitution occurs preferentially at:
- A. 1-position (α -position)
 - B. 2-position (β -position)
 - C. 4-position only
 - D. Both rings equally
16. Which heterocycle is aromatic and basic, because its lone pair on nitrogen does not participate in the aromatic π system?
- A. Pyrrole
 - B. Furan
 - C. Pyridine
 - D. Thiophene
17. Which of the following is antiaromatic?
- A. Cyclobutadiene (4 π electrons, planar)
 - B. Benzene (6 π electrons)
 - C. Cyclopentadienyl anion (6 π electrons)
 - D. Tropylium ion (6 π electrons)
18. Which reagent is commonly used for nitration of benzene?
- A. H_2/Pd
 - B. $\text{HNO}_3 + \text{H}_2\text{SO}_4$
 - C. $\text{Cl}_2 + \text{FeCl}_3$
 - D. Br_2 only
19. Which substituent is an ortho/para director and activating?
- A. $-\text{NO}_2$
 - B. $-\text{Cl}$
 - C. $-\text{OH}$
 - D. $-\text{CF}_3$
20. The major product of bromination of benzene using $\text{Br}_2 / \text{FeBr}_3$ is:
- A. Bromobenzene (via EAS)
 - B. Bromocyclohexane (via addition)
 - C. Bromobenzene plus addition across ring double bonds
 - D. No reaction

Answer ALL QUESTIONS in this section. Ensure that all mechanisms, diagrams, reactions and calculations are neatly shown in your answer booklet. Each question is worth 10 marks.

Question 1**[10 Marks]**

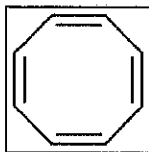
- a) Define alicyclic compound and give two examples. (2 marks)
- b) Explain Baeyer's strain theory of small ring compounds using examples. (3 marks)
- c) Discuss the limitations of Baeyer's strain theory. (2 marks)
- d) Explain, using a diagram, why the cis-decalin conformation is less stable than trans-decalin. (3 marks)

Question 2**[10 Marks]**

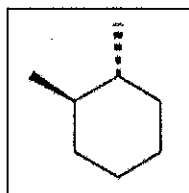
- a) Differentiate angle strain, torsional strain, and steric strain. (3 marks)
- b) Using a diagram, describe the chair conformation of cyclohexane, labelling axial and equatorial bonds. (3 marks)
- c) Draw and explain the effect of 1,3-diaxial interactions on the stability of substituted cyclohexanes. (2 marks)
- d) Explain with a diagram the Gauche butane interaction and how it affects potential energy. (2 marks)

Question 3**[10 Marks]**

- a) State Hückel's rule for aromaticity. (1 mark)
- b) Draw the structure and classify the following as aromatic, antiaromatic, or nonaromatic:
 - (i) Cyclopropenyl cation
 - (ii) Cyclopentadienyl anion
 - (iii) Cyclooctatetraene (3 marks)
- c) Using Frost-Musulin diagram, show the molecular orbital levels for benzene. (1 mark)
- d) Draw and explain why cyclooctatetraene (C_8H_8) adopts a tub conformation instead of being planar. (2 marks)



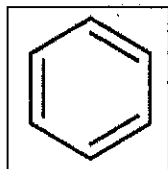
- e) Draw and compare the two possible chair conformations of trans-1,2-dimethylcyclohexane. Indicate which is more stable and why. Ensure to show you methyl groups and the axial and equatorial bonds clearly. (3 marks)



Question 4

[10 Marks]

- a) Write the overall balanced equation for the sulfonation of benzene and name the product.



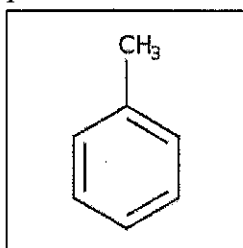
(2 marks)

- b) Draw and label the stepwise mechanism, showing the formation of the electrophile (SO_3H^+) and the σ -complex intermediate. (4 marks)
- c) Explain how the reaction is reversible and how temperature affects sulfonation vs. desulfonation. (2 marks)
- d) Identify the electrophile and the catalyst used in this reaction. (2 marks)

Question 5

[10 Marks]

- a) Draw the nitration mechanism of toluene, showing all major resonance structures of the σ -complex that lead to ortho and para substitution. (4 marks)



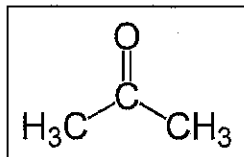
- b) Explain why the $-\text{CH}_3$ group activates the ring and directs substitution to the ortho and para positions. Support your answer with resonance or inductive effects. (2 marks)
- c) Predict the major product of bromination of nitrobenzene, stating the directing effect of the nitro group and showing where substitution occurs. (3 marks)
- d) Identify one meta-directing and one ortho/para-directing group from your examples above. (1 mark)

Answer ALL QUESTIONS in this section. Ensure that all mechanisms, diagrams, reactions and calculations are neatly shown in your answer booklet. Each question is worth 10 marks.

Question 1**[10 Marks]**

A student decided to test her knowledge on the mechanisms of nucleophilic addition to Carbonyl Compounds. Deduce the outcomes of the questions given below.

- a) Draw the full stepwise mechanism showing addition of HCN to acetone (CH_3COCH_3) using curly arrows. Show proton transfers and resonance forms. (8 marks)



- b) Name the intermediate and the nucleophile formed. (2 marks)

Question 2**[10 Marks]**

A student conducted hydrolysis of ethyl acetate ($\text{CH}_3\text{COOCH}_2\text{CH}_3$), an ester, to observe the acid and base catalysed reactions. She obtained the following results:

Reaction Condition	pH Change	Observation	Time Taken for Change
Acid (HCl, 1 M)	Slight decrease (acid formation)	Slight acetic acid smell, slow reaction	8 mins
Base (NaOH, 1 M)	Increase (acetate formation)	Ethanol smell, faster reaction	2 mins

- a) State the functional group of esters. (1 mark)
- b) Why is the reaction faster in base reaction condition than in the acid reaction condition? (1 mark)
- c) What is the difference between acid-catalysed and base-catalysed hydrolysis of esters? (1 mark)
- d) Write balanced equations for both the reactions.
(i) Acid
(ii) Base (2 marks)
- e) Name the process of base-catalysed hydrolysis reactions? (1 mark)

- f) State two ways in which you can monitor the progress of a hydrolysis reaction. (1 mark)
- g) Why is base-catalysed hydrolysis irreversible? (1 mark)
- h) Show the mechanism of carboxylate anion in the base-catalysed reaction. (2 marks)

Question 3

[10 Marks]

A student investigated and compared the solubility, density, and relative reactivity of chlorobenzene and bromobenzene to understand the relation of these properties to their molecular structures. She obtained the following results.

Compound	Solubility in Water	Solubility in Ethanol	Solubility in Hexane	Density relative to Water	Reactivity
Chlorobenzene	Insoluble	Partially soluble	Soluble	Floats ($\rho \approx 1.11$ g/mL)	Unreactive
Bromobenzene	Insoluble	Partially soluble	Soluble	Sinks ($\rho \approx 1.49$ g/mL)	Unreactive

- a) What type of intermolecular forces are present in halogenated aromatic compounds? (1 mark)
- b) Why are Chlorobenzene and Bromobenzene insoluble in water but soluble in Hexane? (2 marks)
- c) What accounts for the difference in the density between Bromobenzene and Chlorobenzene? (1 mark)
- d) Differentiate between aryl halides and alkyl halides? (1 mark)
- e) Explain why aryl halides are much less reactive toward nucleophilic substitution compared to alkyl halides. (1 mark)
- f) Draw the respective resonance structures for Chlorobenzene and Bromobenzene showing how the halogen atom interacts with the benzene ring.
- (i) Chlorobenzene (2 marks)
- (ii) Bromobenzene (2 marks)

PERIODIC TABLE OF ELEMENTS

PERIODIC TABLE OF ELEMENTS																			
1	2																		
H Hydrogen	He Helium																		
3	4	5													6	7	8	9	10
Li Lithium	Be Beryllium	B Boron													C Carbon	N Nitrogen	O Oxygen	F Fluorine	Ne Neon
11	12	13													14	15	16	17	18
Na Sodium	Mg Magnesium	Al Aluminium													Si Silicon	P Phosphorus	S Sulfur	Cl Chlorine	Ar Argon
19	20	21	22	23	24	25	26	27	28	29	30	31	32	33	34	35	36		
K Potassium	Ca Calcium	Sc Scandium	Ti Titanium	V Vanadium	Cr Chromium	Mn Manganese	Fe Iron	Co Cobalt	Ni Nickel	Cu Copper	Zn Zinc	Ga Gallium	Ge Germanium	As Arsenic	Se Selenium	Br Bromine	Kr Krypton		
37	38	39	40	41	42	43	44	45	46	47	48	49	50	51	52	53	54		
Rb Rubidium	Sr Strontium	Y Yttrium	Zr Zirconium	Nb Niobium	Mo Molybdenum	Tc Technetium	Ru Ruthenium	Rh Rhodium	Pd Palladium	Ag Silver	Cd Cadmium	In Indium	Sn Tin	Sb Antimony	Te Tellurium	I Iodine	Xe Xenon		
55	56	57	72	73	74	75	76	77	78	79	80	81	82	83	84	85	86		
Cs Cesium	Ba Barium	La Lanthanum	Hf Hafnium	Ta Tantalum	W Tungsten	Re Rhenium	Os Osmium	Ir Iridium	Pt Platinum	Au Gold	Hg Mercury	Tl Thallium	Pb Lead	Bi Bismuth	Po Polonium	At Astatine	Rn Radon		
87	88	89	104	105	106	107	108	109	110	111	112	113	114	115	116	117	118		
Fr Francium	Ra Radium	Ac Actinium	Rf Rutherfordium	Db Dubnium	Sg Seaborgium	Bh Bohrium	Hs Hassium	Mt Meitnerium	Ds Darmstadtium	Rg Roentgenium	Cn Copernicium	Nh Nihonium	Fl Flerovium	Mc Moscovium	Lv Livermorium	Ts Tennessine	Og Oganesson		

58	Ce Cerium	59	Pr Praseodymium	60	Nd Neodymium	61	Pm Promethium	62	Sm Samarium	63	Eu Europium	64	Gd Gadolinium	65	Tb Terbium	66	Dy Dysprosium	67	Ho Holmium	68	Er Erbium	69	Tm Thulium	70	Yb Ytterbium	71	Lu Lutetium
90	Th Thorium	91	Pa Protactinium	92	U Uranium	93	Np Neptunium	94	Pu Plutonium	95	Am Americium	96	Cm Curium	97	Bk Berkelium	98	Cf Californium	99	Es Einsteinium	100	Fm Fermium	101	Md Mendelevium	102	No Nobelium	103	Lr Lawrencium

THE END

