Annexe A: New/Revised Course Content in OBTL+ Format

Course Overview

Expected Implementation in Academic Year	AY2025-2026
Semester/Trimester/Others (specify approx. Start/End date)	Semester 1
Course Author * Faculty proposing/revising the course	Richard Webster, Ye Hui
Course Author Email	webster@ntu.edu.sg; ye.hui@ntu.edu.sg
Course Title	Analytical Chemistry
Course Code	CM2011
Academic Units	3
Contact Hours	39
Research Experience Components	Not Applicable

Course Requisites (if applicable)

Pre-requisites	(CM1021 and CM1041) or CM9001 or CM5000 or CM1001 or CY1101 or (BS1012 and BS1022)
Co-requisites	
Pre-requisite to	
Mutually exclusive to	MS2003 and MS2013
Replacement course to	
Remarks (if any)	

Course Aims

The lectures provide an introduction to modern analytical methods that are used to quantify species and instrumental methods used to monitor the progress of reactions. The course comprises a mixture of numerical problem solving and descriptive chemical analysis.

Course's Intended Learning Outcomes (ILOs)

Upon the successful completion of this course, you (student) would be able to:

ILO 1	Errors and Confidence Interval a. Explain the difference between absolute, relative and percent relative uncertainties. b. Discuss how errors are totaled when numbers (with errors) are combined. c. Apply and calculate the confidence interval. d. Apply the Q-test to exclude points. e. Explain when to use the correct number of significant figures and correct rounding. f. Execute the student t-test to compare different sets of data for three cases: (a) Comparing a measured result with a 'known' value. (b) Comparison of the means of two methods. (c) Paired t test for comparing individual differences
ILO 2	Air Pollution Measurements in Singapore a. Identify the differences between Air Quality Index (AQI) and Pollutant Standards Index (PSI). b. Discuss the major pollutants that are measured. c. Discuss how data from the NEA website is interpreted. d. Discuss how to calculate PSI from raw data. e. Explain how "cigarette scale" can be used to understand PM values. f. Describe how the elemental concentrations of PM are measured.
ILO 3	Introductory Electrochemistry a. Discuss the concept of ionic strength and how to calculate activities and activity coefficients. b. Analyse activity coefficients to calculate solubility products. c. Explain how to draw an electrochemical cell in shorthand notation. d. Describe how to calculate the cell potential and direction of the spontaneous reaction of two half-cell reactions. e. Explain how the Nernst equation can be used to calculate cell potentials when activities are less than unity.

ILO 4	Potentiometry a. Explain how the pH electrode functions, which equilibrium reactions occur, and the importance of ionic strength. b. Discuss how to write an ISE cell in short hand notation. c. Identify all of the potentials that operate in an ISE (interfacial potentials and junction potentials). d. Discuss the operation of the major types of ISEs (glass, single crystal, pressed powder and polymer membrane). e. Describe the practical limitations of ISEs and how to calculate selectivity coefficients.
ILO 5	Molecular Absorption Spectroscopy a. Explain how to convert between different units of measurement used for spectroscopy. b. Discuss the difference between rotational, vibration and electronic energy levels. c. Explain the calculations based on Beer's law (A = bc) and Scatchard plots. d. Discuss the different components of an Absorption spectrometer and how they function (excitation source, monochromator, sample holders, detector).
ILO 6	Molecular Florescence (Emission) Spectroscopy a. Discuss the similarities and differences between molecular fluorescence and absorption instrumentation. b. Describe molecular fluorescence and phosphorescence electronic transitions (vibrational relaxation, internal conversion, intersystem crossing). c. Explain stokes shift. d. Describe the quantum yield. e. Discuss why fluorescence measurements are very sensitive.
ILO 7	Atomic Spectroscopy: a. Discuss the differences between atomic and molecular spectroscopy. b. Identify the differences between Atomic Absorption Spectroscopy (AAS) and Atomic Emission Spectroscopy (AES). c. Explain how a hollow cathode lamp functions. d. Discuss why AES is more sensitive to temperature than AAS. e. Identify the causes of line broadening.

ILO 8	Extractions a. Explain how to extract a solute from one phase into another in which it is more soluble. b. Apply the partition coefficient to determine ratio of solute concentrations in each phase at equilibrium. c. Apply distribution coefficient when more than one form of solute exists in each phase at equilibrium. d. Derive equations relating the fraction of solute extracted to the partition or distribution coefficient, volumes, and pH. e. Explain how the number of extractions relate to efficiency of extractions. f. Describe how the metal chelator can extract metal ions from aqueous solutions. g. Explain how crown ethers and salts containing a hydrophobic ion act as phase transfer agents
ILO 9	General Chromatography a. Describe the equilibration of solute between mobile and stationary phase in adsorption and partition chromatography. b. Describe the stationary phase of packed columns and open tubular columns. c. Explain the separation process in ion-exchange and ion chromatography. d. Explain the separation process in molecular exclusion chromatography. e. Explain how solutes interact with the stationary phase in affinity chromatography. f. Describe the relative retention and adjusted retention times in chromatography. g. Describe the retention factor for a single component in chromatography. h. Explain how to scale up a separation from a small load to a large load. i. Describe the relationship between plate height and band emerging from column. j. Describe resolution in terms of average width of peaks and number of plates. k. Discuss how relative retention affects chromatographic resolution. l. Explain the standard deviation of a diffusing band of solute. m. Describe band broadening using the terms in the van Deemter equation. n. Discuss band spreading during injection, detection, in connecting tubing, and during passage through the separation column. o. Explain the cause of fronting and tailing in chromatography, and how to prevent them.

ILO 10	Gas Chromatography a. Describe the stationary and mobile phases in gas chromatography. b. Explain the resolution from wall-coated, porous and packed columns. c. Explain temperature and pressure programming. d. Discuss the separation efficiency with respect to hydrogen, helium and nitrogen carrier gases. e. Explain split injection, splitless injection and on-column injection and their advantages and disadvantages. f. Discuss the use of internal standards in gas chromatography. g. Describe thermal conductivity detection, flame ionization detection, electron capture detection. h. Discuss the methods in chromatographic development.
ILO 11	High-Performance Liquid Chromatography a. Describe the stationary and mobile phases in high-performance liquid chromatography (HPLC). b. Discuss how the particle size and its polarity affects column efficiency. c. Explain the difference between normal-phase and reversed-phase chromatography. d. Discuss the polarity of solvent used in HPLC. e. Discuss the difference between reversed-phase and hydrophilic interaction columns. f. Explain gradient elution process in separation of solutes with different polarities. g. Describe the functions of the guard column, pump, oven, and detector in HPLC. h. Explain the working principles of ultraviolet detection, refractive index detection, evaporative light scattering detector, electrochemical and fluorescence detectors.

Course Content

S/N	Topic	Approx. Lecture Hours
1	Errors and Confidence Interval: Common analytical problems, statistical treatment, accuracy and precision, significant figures, Gaussian distribution, confidence interval, student's t tests and Q test.	3
2	Air Pollution Measurements in Singapore: Pollutants Standards Index (PSI), Air Quality Index (AQI), particles in the atmosphere, PM2.5 and PM10, elemental analysis, platinum and rare earth group elements, local events, haze, enrichment factors and organic pollutants.	2
3A	Introductory Electrochemistry: Fundamentals, ionic strengths, activities and activity coefficients, electrode and cell potentials, the Nernst equation and concentration (activity) dependence.	5
3B	Potentiometry: Chemical sensors, ion-selective electrodes, glass membrane electrodes, liquid junction potentials, inorganic salt membranes, polymer membranes and selectivity coefficients.	3
4A	Molecular Absorption Spectroscopy: Electromagnetic radiation, electronic transitions, Beer-Lambert law and instrumentation.	2
4B	Molecular Florescence (Emission) Spectroscopy: Instrumentation, fluorescence and phosphorescence, Stokes shift and quantum yield.	2
4C	Atomic Spectroscopy: Absorption and emission, instrumentation, inductively coupled plasma (ICP), temperature effects and atomic linewidths.	2
5	Extractions: Solvent extractions, efficiency, pH effects, extraction with a metal chelator, transfer agents.	3
6	General Chromatography: Types of chromatography, chromatogram, retention parameters, retention time, partition coefficient, scaling up, resolution, diffusion, plate height, factors affecting resolution, broadening outside the column, plate height equation, longitudinal diffusion, finite equilibration time between phases, multiple flow paths, advantages of open tubular columns, asymmetric peaks.	5
7	Gas Chromatography: Separation process, open tubular columns, common stationary phases, packed columns, retention, temperature and pressure programming, carrier gas, guard columns and retention gaps, sample injection, split injection, splitless injection, on-column injection, detectors, thermal conductivity detector, flame ionization detector, electron capture detector, gas-chromatography-mass spectrometry, sample preparation, method development.	4
8	High-Performance Liquid Chromatography: Chromatographic process, scaling between columns, performance as function of particle diameter, column, stationary phase, elution process, isocratic and gradient elution, hydrophilic interaction chromatography, injection and detection, pumps and injection valves, spectrophotometric detectors, evaporative light-scattering detector, charged aerosol detector, electrochemical detector, refractive index detector, optimization of isocratic retention, pH effects, gradient separations.	4

Reading and References (if applicable)

D. A. Skoog, D. M. West, F. J. Holler and S. R. Crouch "Fundamentals of Analytical Chemistry (9th Edition)", Brooks/Cole, Cengage Learning, 2014. ISBN: 9780495558286

Reference textbook: D. C. Harris and C. A. Lucy “Quantitative Chemical Analysis (9th Edition)", W. H. Freeman and Company, 2016. ISBN: 9781319154141

Planned Schedule

Week or Session	Topics or Themes	ILO	Readings	Delivery Mode	Activities
1	Errors and Statistics	1			Lecture and online
2	Environmental Chemistry	2			Online content
3	Introductory Electrochemistry	3			Online content
4	Introductory Electrochemistry / Chemical sensors	3, 4a to 4c			Online content
5	Chemical sensors	4			Online content
6	Mid-term Test 1 / Molecular Spectrophotometry	5			Lecture and online content
7	Molecular Spectrophotometry / Atomic Spectroscopy	6,7			Online content
8	Extractions	8			Lecture and online
9	General Chromatography	9a to 9g			Lecture and online
10	General Chromatography / Gas Chromatography	9h to 9o, 10a to 10c			Lecture and online
11	Gas Chromatography	10d to 10h			Lecture and online
12	Mid-term Test 2 / High-Performance Liquid Chromatography	11a to 11c			Lecture and online

Week or Session	Topics or Themes	ILO	Readings	Delivery Mode	Activities
13	High-Performance Liquid Chromatography	11d to 11i			Lecture and online

Learning and Teaching Approach

Approach	How does this approach support you in achieving the learning outcomes?
Blend of online and face-to- face lectures.	The bulk of the content will be delivered online. This allows (a) extensive use of animations and laboratory videos and (b) use of interactive questions so that students may immediately test their learning. Face to face lectures and experimental demonstrations will be employed for selected topics.

Assessment Structure

Assessment Components (includes both continuous and summative assessment)

No.	Component	ILO	Related PLO or Accreditation	Weightage	Description of Assessment Component	Team/Individual	Rubrics	Level of Understanding
1	Continuous Assessment (CA): Test/Quiz(Midterm 1)	1-7	Competence, Creativity	20		Individual	Analytic	Multistructural
2	Continuous Assessment (CA): Test/Quiz(Midterm 2)	8-9	Competence, Creativity	15		Individual	Analytic	Multistructural
3	Continuous Assessment (CA): Class Participation(Quiz)	1-9 (depending on week)	Competence, Creativity	5		Individual	Holistic	Multistructural
4	Summative Assessment (EXAM): Final exam()	1-9	Competence, Creativity	60		Individual	Analytic	Multistructural

Description of Assessment Components (if applicable)

Midterm 1: Tests under exam conditions. MCQ or short answer questions.

Midterm 2: Tests under exam conditions. MCQ or short answer questions.

In-class Quiz: One or two online questions during each class to test understanding of the current topic. Students must attend class in person, and full marks will be given for participation.

Final Exam: Closed-book exam consisting of short answer questions and calculations (see past years' examinations for format).

Formative Feedback

You will be given feedback in four ways:

1. By response to postings on the course discussion board.

2. Through the marking of the mid-terms.

3. Through one-on-one discussions via appointment with the course instructor

4. General feedback will be provided to the students following the final exam.

NTU Graduate Attributes/Competency Mapping

This course intends to develop the following graduate attributes and competencies (maximum 5 most relevant)

Attributes/Competency	Level
Digital Fluency	Basic
Critical Thinking	Basic
Systems Thinking	Basic

Course Policy

Policy (Academic Integrity)

Good academic work depends on honesty and ethical behaviour. The quality of your work as a student relies on adhering to the principles of academic integrity and to the NTU Honour Code, a set of values shared by the whole university community. Truth, Trust and Justice are at the core of NTU's shared values. As a student, it is important that you recognize your responsibilities in understanding and applying the principles of academic integrity in all the work you do at NTU. Not knowing what is involved in maintaining academic integrity does not excuse academic dishonesty. You need to actively equip yourself with strategies to avoid all forms of academic dishonesty, including plagiarism, academic fraud, collusion and cheating. If you are uncertain of the definitions of any of these terms, you should go to the academic integrity website for more information. On the use of technological tools (such as Generative AI tools), different courses / assignments have different intended learning outcomes. Students should refer to the specific assignment instructions on their use and requirements and/or consult your instructors on how you can use these tools to help your learning. Consult your instructor(s) if you need any clarification about the requirements of academic integrity in the course.

Policy (General)

You are expected to complete all online activities in good time.

Policy (Absenteeism)

If you miss a lecture, you are expected to make up for the lost learning activities. If you miss one of the mid-term tests with a valid reason and approval (such as a medical certificate), then the total CA will come from the other mid-term test. If you miss both mid-term tests with a valid reason then an additional make-up test will be set to obtain the total CA mark.

Policy (Others, if applicable)

Diversity and Inclusion Policy

Integrating a diverse set of experiences is important for a more comprehensive understanding of science and engineering.

It is our goal to create an inclusive and collaborative learning environment that supports a diversity of perspectives and learning experiences. That honours your identities; including ethnicity, gender, socioeconomic status, sexual orientation, religion or ability.

To help accomplish this:

- If you are neuroatypical or neurodiverse, have dyslexia or ADHD (for example), or have a social anxiety disorder or social phobia;
- If you feel your performance in the course is being impacted by your experiences outside of class;
- If something was said in the course (by anyone, including instructor/supervisor) that made you uncomfortable.

Please e-mail to your Associate Chair (Students & Continuing Education) at ac-cceb-stud@ntu.edu.sg about how we can help facilitate your learning experience.

As a participant in course discussions you should also strive to honour the diversity of your classmates. You can do this by; using preferred pronouns and names; being respectful of others opinions and actively making sure all voices are being heard; and refraining from the use of derogatory or demeaning speech or actions.

All members of the course are expected to strictly adhere to the student code of conduct (https://www.ntu.edu.sg/life-at-

ntu/student-life/student-conduct) . If you witness something that goes against this or have any other concerns, please speak to your instructors or a faculty member.

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Last Updated By: Natasha Bhatia (Dr)