Indian Institute of Technology, Kanpur

Proposal for A New Course

1. Course No: **CHM6XX**
2. Course Title: **Electrodics, Electroanalytical, and Electrocatalysis**
3. Per Week Lectures: **3** (L), Tutorial: 0 (T), Laboratory: 0 (P), Additional Hours[0-2]: **2** (A), Credits (3*L+2*T+P+A): **9** Duration of Course: Full Semester
4. Proposing Department/IDP: **Department of Chemistry**

   Other Departments/IDPs which may be interested in the proposed course: **MSE, CHE, ME, CE, SEE,** and **BSBE**

   Other faculty members interested in teaching the proposed course: **Raja Angamuthu** and **Prakash C. Mondal**

5. Proposing Instructor: **Anantharaj Sengeni,** Assistant Professor of Chemistry.
6. Course Description: This course provides a comprehensive understanding of electrochemical principles and their applications in energy conversion and electroanalytical techniques. The focus will be on electrochemical kinetics, electrocatalysis of several important energy conversion reactions and sensors (including electrochemical biosensors), and advanced electroanalytical methods used for evaluating electrochemical systems. The aim is to equip students with both the theoretical background and practical skills needed to work in electrochemical energy systems, electrochemical sensors, and analytical applications.

A) Objectives:

- To understand the fundamentals of electrochemistry, including thermodynamics and kinetics.
- To provide a comprehensive overview of electroanalytical techniques, including cyclic voltammetry, chronoamperometry, electrochemical impedance spectroscopy (EIS), and others.
- To explore various electrochemical systems and their relevance in energy conversion.
- To study the principles and mechanisms of electrocatalysis, focusing on water electrolysis reactions, fuel cell reactions, CO_2 and N_2 electrolyzer reactions.
- To study advanced electrochemical biosensor technologies for diagnostics.

- To critically analyze electrochemical performance and durability of materials used in energy and sensor applications.
- To learn the best practices in handling electrochemical characterization techniques and the data thereof

B) Contents (preferably in the form of 5 to 10 broad titles):

S. No	Broad Title	Topics	No. of Lectures
1.	Fundamentals of Electrochemistry	• Introduction to electrochemistry: Nernst equation, thermodynamics, and potentials. • Electrochemical cells and standard reduction potentials. • Ion transport and mass transfer in electrochemical systems. • Double-layer structure and its influence on electrode reactions.	6
2.	Electrodics	• Butler-Volmer equation and Tafel analysis. • Charge transfer processes and reaction mechanisms. • Diffusion and convection: Fick's laws and related equations. • Kinetics of multi-step reactions and mixed potential theory.	5
3.	Electroanalytical Techniques	• Cyclic voltammetry (CV): Interpretation of current-voltage profiles. • Chronoamperometry and chronopotentiometry. • Electrochemical impedance spectroscopy (EIS): Basics and data fitting. • Rotating disk electrode (RDE) and rotating ring-disk electrode (RRDE) techniques. • In-situ and operando techniques in electrocatalysis.	10

4.	Electrocatalysis and Energy Conversion Reactions	• Electrocatalysis of oxygen evolution (OER), hydrogen evolution (HER), hydrogen oxidation (HOR), oxygen reduction reaction (ORR), CO_2 reduction, and N_2 & NO_x reduction. • Mechanistic insights into electrocatalytic energy conversion processes.	6
5.	Electrochemical Biosensors	• Principles of biosensing: Enzymatic and non-enzymatic sensors. • Electrochemical transduction methods (amperometric, potentiometric, impedimetric). • Nanomaterials in biosensor design and application.	5
6.	Best Practices in Handling Electrochemical Techniques/Data	• Importance of reproducibility and accuracy in electrochemical experiments. • Common pitfalls and errors in interpreting data. • Strategies for proper selection of reference electrodes, electrolytes, and measurement conditions. • Reporting standards for electrochemical performance: Polarization curves, Tafel slopes, and impedance data.	6
7.	Advanced Topics and Special Lectures	• Case studies: Real-world applications of electrocatalysis and biosensing. • Guest lectures on cutting-edge electrochemical research.	4

C) Pre-requisites, if any: **Nil**

D) Short summary for including in the Courses of Study Booklet:
This course delves into electrochemical fundamentals, kinetics, electrocatalysis, and advanced energy conversion reactions (such as HER, OER, ORR, CO_2 and nitrogen reduction reactions). It also covers the design and application of

electrochemical biosensors and introduces key electroanalytical techniques. A module on best practices for electrochemical characterization ensures students gain proficiency in reproducible experimentation. This course is ideal for PG students in chemistry and materials science fields, emphasizing both theory and practical applications.

7. Recommended References:
    a. Textbooks:
        i. "Electrochemical Methods: Fundamentals and Applications" by A.J. Bard and L.R. Faulkner.
        ii. "Modern Electrochemistry" by J.O'M. Bockris and A.K.N. Reddy.
        iii. "Biosensors: Fundamentals and Applications" by Anthony P.F. Turner.
        iv. "Fuel Cell Fundamentals" by Ryan O'Hayre et al.
    b. Others important literature reports:
        i. Anantharaj *et. al.,* How Reliable Are the Overpotentials Reported in Energy Conversion Electrocatalysis? Catal. Sci. Technol., 2024, 14 (8), 2025-2039.
        ii. Anantharaj *et. al.,* Ambiguities and best practices in the determination of active sites and real surface area of monometallic electrocatalytic interfaces Journal of Colloid and Interface Science, 2023, 634, 169-175.
        iii. S. Anantharaj* and S. Noda, The importance of carefully choosing vertex potentials in hydrogen underpotential deposition Materials Today Energy, 2023, 32, 101234.
        iv. Anantharaj *et. al.*, The Reference Electrode Dilemma in Energy Conversion Electrocatalysis: "Right vs Okay vs Wrong", Journal of Materials Chemistry A, 2023, 11, 17699-17709.
        v. S. Anantharaj* and S. Noda, How properly are we interpreting the Tafel lines in energy conversion electrocatalysis? Materials Today Energy, 2022, 29, 101123.
        vi. S. Anantharaj* and S. Noda, Dos and don’ts in screening water splitting electrocatalysts, Energy Advances 2022,1, 511-523.
        vii. S. Anantharaj* and S. Noda, iR drop correction in electrocatalysis: everything one needs to know!, Journal of Materials Chemistry A 2022, 10, 9348-9354.
        viii. Anantharaj *et. al.,* Why shouldn’t double-layer capacitance (C_{dl}) be always trusted to justify Faradaic electrocatalytic activity differences? Journal of Electroanalytical Chemistry 2021, 903, 115842.
        ix. Anantharaj *et. al.,* The Significance of Properly Reporting Turnover Frequency in Electrocatalysis Research! Angewandte Chemie Int. Ed., 2021, 60, 23051-23067.

x. Anantharaj et al., Alternating Current Techniques for a Better Understanding of Photoelectrocatalysts, ACS Catalysis 2021, 11, 20, 12763–12776.
xi. Anantharaj *et. al.,* The Pitfalls of Using Potentiodynamic Polarization Curves for Tafel Analysis in Electrocatalytic Water Splitting, ACS Energy Lett., 2021, 6, 4, 16071-1611.
xii. S. Anantharaj,* and S. Noda, Appropriate Use of Electrochemical Impedance Spectroscopy in Water Splitting Electrocatalysis, ChemElectroChem 2020, 7, 2297-2308.
xiii. S. Anantharaj,* and S. Kundu*, Do the Evaluation Parameters Reflect Intrinsic Activity of Electrocatalysts in Electrochemical Water Splitting?, ACS Energy Letters 2019, 4, 6, 1260–1264.
xiv. Anantharaj *et. al.,* Precision and correctness in the evaluation of electrocatalytic water splitting: revisiting activity parameters with a critical assessment, Energy and Environmental Science, 2018, 11, 744-771.

8. Any other remarks: **Nil**

Dated: 21-09-2024 Proposer: 

Dated: **23.09.2024** DPGC Convener (CHM): 

This course is approved / not approved

Chairman, SPGC

Dated: