



COURSE DESCRIPTION CARD - SYLLABUS

Course name

REDOX OR NON-REDOX... THAT IS THE QUESTION - TOWARDS UNDERSTANDING ELECTROCHEMISTRY AND ENERGY CONVERSION/STORAGE PROCESSES [S5NC>RNRO]

Course

Proposed by Discipline

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Year/Semester

2/3

Level of study

Doctoral School

Course offered in

English

Form of study

full-time

Requirements

elective

Number of hours

Lecture

8

Laboratory classes

0

Other

0

Tutorials

0

Projects/seminars

0

Number of credit points

8,00

Coordinators

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Lecturers

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Prerequisites

Basic knowledge of physical chemistry, thermodynamics, and electrochemistry is recommended. Previous experience in electrochemical energy storage research is not required. Doctoral students from different scientific disciplines are encouraged to participate.

Course objective

The course aims to develop an advanced understanding of electrochemical energy conversion and storage processes, with particular emphasis on the fundamental distinction between Faradaic (redox) and non-Faradaic charge storage mechanisms. The course critically examines the physical and chemical foundations of electrode processes, the role of electrode–electrolyte interfaces, and the relationship between thermodynamics, kinetics, and experimentally observed electrochemical behaviour. Particular attention is given to the challenges of identifying charge storage mechanisms and distinguishing between electrostatic, pseudocapacitive, and battery-type responses. By combining fundamental concepts with examples from contemporary research, the course encourages doctoral students to question conventional classifications, critically interpret experimental evidence, and formulate scientifically justified conclusions.

Course-related learning outcomes

Knowledge

K1 Understands the fundamental thermodynamic, kinetic, and interfacial principles governing Faradaic and non-Faradaic electrochemical processes. P8S_WG / SzD_W01

K2 Knows contemporary approaches to electrochemical energy storage and major scientific challenges concerning charge storage mechanisms, electrode materials, and electrolyte interactions. P8S_WG / SzD_W02

K3 Understands the principles, capabilities, and limitations of experimental methods used to investigate electrochemical processes and charge storage mechanisms. P8S_WG / SzD_W03

Skills

S1 Can critically analyse electrochemical data, identify possible charge storage mechanisms, and distinguish between experimentally demonstrated phenomena and proposed interpretations. P8S_UW / SzD_U02

S2 Can formulate a scientifically justified hypothesis and propose an appropriate experimental strategy to investigate an unresolved electrochemical problem. P8S_UW / SzD_U01

S3 Can communicate and defend scientific interpretations using appropriate terminology, experimental evidence, and peer-reviewed literature. P8S_UK / SzD_U04, SzD_U07

Social competencies

SC1 Is ready to critically assess established interpretations, scientific publications, and emerging concepts in electrochemical energy research. P8S_KK / SzD_K01

SC2 Recognises the importance of scientific integrity, responsible interpretation of experimental results, and acknowledgement of uncertainty in scientific research. P8S_KR / SzD_K07

Methods for verifying learning outcomes and assessment criteria

Learning outcomes presented above are verified as follows:

Learning outcomes are verified through an individual scientific case study and a short scientific discussion. The assessment focuses on the ability to apply fundamental electrochemical knowledge to a selected scientific problem rather than reproduce theoretical definitions.

Individual scientific case study (80% of final grade)

Each doctoral student prepares a concise critical analysis (approximately 1,500–2,000 words) addressing a selected problem related to electrochemical energy conversion or storage. The topic may be selected from examples proposed by the lecturer or developed in relation to the student's own research interests.

The case study should include:

- Definition of the scientific problem and identification of the relevant electrochemical phenomena.
- Critical analysis of selected peer-reviewed publications or experimental data.
- Discussion of the underlying charge storage or charge transfer mechanisms, including uncertainties and alternative interpretations.
- Proposal of an experimental approach that could verify the scientific hypothesis or distinguish between competing mechanisms.
- Scientifically justified conclusions supported by appropriate references.

Scientific discussion (20% of final grade)

During a short individual discussion, the doctoral student explains and defends the main conclusions of the case study, addresses methodological limitations, and responds to questions concerning alternative interpretations and experimental verification.

Assessment criteria

Scientific accuracy and understanding of electrochemical mechanisms 25% K1, K2

Critical interpretation of scientific evidence and recognition of uncertainty 25% S1, SC1, SC2

Quality and feasibility of the proposed experimental strategy 25% K3, S2

Quality of scientific argumentation, literature use, and discussion 25% S3, SC1

The first three criteria are assessed through the written case study, and the fourth criterion comprises 5% from the written work and 20% from the scientific discussion.

All assessment criteria and their weighting are communicated to doctoral students at the beginning of the course. Individual feedback identifies strengths, scientific inaccuracies, and areas requiring improvement.

The final grade is determined according to the following scale:

Total assessment score Grade

Above 90% to 100% 5.0 – Very good

Above 80% to 90% 4.5 – Good plus
Above 70% to 80% 4.0 – Good
Above 60% to 70% 3.5 – Satisfactory plus
Above 50% to 60% 3.0 – Satisfactory
50% or below 2.0 – Unsatisfactory

The assessment requires demonstrated achievement of the intended learning outcomes. The lecturer reviews the effectiveness of assessment methods using the quality of submitted work and student feedback to support continuous improvement.

Programme content

The course addresses the fundamental concepts and contemporary scientific challenges associated with electrochemical energy conversion and storage.

The central theme is the distinction between redox and non-redox processes, approached through thermodynamic, kinetic, and interfacial perspectives. Particular attention is devoted to the interpretation of charge storage mechanisms and the limitations of conventional classifications.

Selected examples from electrical double-layer capacitors, pseudocapacitive systems, rechargeable batteries, and hybrid electrochemical devices illustrate how the same experimental response may arise from different physical and chemical processes.

The course discusses commonly employed electrochemical characterisation methods and critically examines their ability to provide mechanistic evidence. Special emphasis is placed on identifying misconceptions, distinguishing correlation from causation, and designing experiments that enable competing scientific interpretations to be tested.

Course topics

Lecture 1

Electrochemical energy storage: what actually stores the charge?

Thermodynamics of electrochemical systems; electrode potentials and electrochemical equilibria; Faradaic versus non-Faradaic processes; electrical double-layer formation; the meaning and limitations of conventional classifications.

Lecture 2

Between batteries and capacitors: challenging established classifications

Charge storage mechanisms in porous electrodes; surface redox reactions; pseudocapacitance; ion adsorption and intercalation; electrode–electrolyte interactions; capacitive and battery-type electrochemical signatures.

Lecture 3

Can we trust electrochemical data? Methods, interpretations, and misconceptions

Cyclic voltammetry, galvanostatic methods, electrochemical impedance spectroscopy, and complementary operando techniques; identifying kinetic and transport limitations; ambiguous experimental signatures; the distinction between evidence and interpretation.

Lecture 4

Beyond textbook electrochemistry: open questions and future research directions

Emerging energy storage concepts; coupling between electrode structure, electrolyte properties, and charge storage; scientific controversies; experimental verification of competing hypotheses; selected research case studies and interactive discussion.

Teaching methods

Interactive lectures supported by scientific literature, experimental data, and selected research case studies. Problem-oriented discussions and critical comparisons of alternative mechanistic interpretations are used to encourage independent scientific reasoning. Doctoral students are invited to relate the discussed concepts to their own research fields.

Individual work based on a selected scientific case study complements the lectures and provides an opportunity to apply acquired knowledge to an authentic research problem.

Bibliography

Basic

1. Bard, A. J., Faulkner, L. R., and White, H. S., *Electrochemical Methods: Fundamentals and Applications*, 3rd ed., Wiley, 2022.
2. Conway, B. E., *Electrochemical Supercapacitors: Scientific Fundamentals and Technological Applications*, Springer, 1999.
3. Bockris, J. O'M., Reddy, A. K. N., and Gamboa-Aldeco, M., *Modern Electrochemistry 2A: Fundamentals of Electrodics*, 2nd ed., Springer, 2000.

Additional

1. Simon, P., and Gogotsi, Y., "Materials for electrochemical capacitors", *Nature Materials*, 7, 845–854 (2008). DOI: 10.1038/nmat2297.
 2. Augustyn, V., Simon, P., and Dunn, B., "Pseudocapacitive oxide materials for high-rate electrochemical energy storage", *Energy & Environmental Science*, 7, 1597–1614 (2014). DOI: 10.1039/C3EE44164D.
 3. Brousse, T., Bélanger, D., and Long, J. W., "To Be or Not To Be Pseudocapacitive?", *Journal of The Electrochemical Society*, 162, A5185–A5189 (2015). DOI: 10.1149/2.0201505jes.
 4. Gogotsi, Y., and Penner, R. M., "Energy Storage in Nanomaterials – Capacitive, Pseudocapacitive, or Battery-like?", *ACS Nano*, 12, 2081–2083 (2018). DOI: 10.1021/acsnano.8b01914.
- Additional peer-reviewed publications reflecting recent developments in electrochemical energy storage will be provided during the course.

Breakdown of average student's workload

	Hours	ECTS
Total workload	50	2,00
Classes requiring direct contact with the teacher	8	0,50
Doctoral student's own work (literature studies, preparation for laboratory classes/tutorials, preparation for tests/exam, project preparation)	42	1,50