

# UNIVERSITÀ DEGLI STUDI DI MILANO-BICOCCA

# COURSE SYLLABUS

# Non Equilibrium Thermodynamics

2324-1-F5401Q068

#### **Aims**

The aim of the course is to provide students with a modern conceptual framework of the thermodynamics of systems out of equilibrium. Examples of notable applications wil be given.

#### Knowledge and understanding

- Use of proper theoretical models in the analysis of out-of-equilibrium systems
- Procedures to compute non-equilibrium thermodynamic quantities
- · Criteria for the evaluation of stability in out-of-equilibrium thermodynamic systems

#### Applying knowledge and understanding

- · Writing evolutionary equations of non-equilibrium thermodynamic systems
- · Analysis of the connections between thermodynamics and statistical mechanics out of equilibrium
- · Tools to analyze energy conversion systems also in view of their sustainability

## Making judgments

- Development of critical capacities in the use of non-equilibrium thermodynamic potentials
- · Ability to critically analyze thermodynamic theories

#### Communication skills

Rigorous use of natural language in science

## Learning skills

Activation of critical skills in the analysis of scientific models

#### **Contents**

Equilibrium thermodynamics from a superior point of view. Near.equilibrium thermodynamics. Heat engines out of equilibrium. Far-from-equilibrium thermodynamics. Dynamic systems.

# **Detailed program**

#### **Equilibrium Thermodynamics from a Superior Point of View**

Scope and Definitions; The Fundamental Laws; Gibbs' Equation; Fundamental Relations and State Equations; Euler's Relation; Gibbs—Duhem's Relation; Legendre Transformations and Thermodynamic Potentials; Extremum Principles; Stability of Equilibrium States; Equilibrium Chemical Thermodynamics.

#### **Near-Equilibrium Thermodynamics**

Basic Concepts; Local Equilibrium Hypothesis; Entropy Balance; Evolution Equations; Stationary States; Applications to Heat Conduction and Mass Transport; Limitations of the Classical Theory of Irreversible Thermodynamics. Coupled Transport Phenomena: Electrical Conduction; Thermoelectric Effects; Thermodiffusion; Diffusion Through a Membrane.

#### **Heat Engines out of equilibrium**

Finite-Time Thermodynamics; The Finite-Time Carnot Cycle and the Curzon–Ahlborn's Model; Exo-reversible and Endo-reversible Heat Engines. Sustainability from the thermodynamic viewpoint.

#### Far-from-equilibrium Thermodynamics

Scope of Extended Irreversible Thermodynamics; Fourier's vs. Cattaneo's Law of Heat Conduction; Extended Entropy; Application to Steady Heat Transport in Nano-Systems. Einstein's Formula and the Second Moments of Equilibrium Fluctuations; Derivation of the Onsager–Casimir's Reciprocal Relations; Fluctuation–Dissipation Theorem; Brownian Motion with Inertia.

#### **Dynamic Systems**

Chemical Reactions and Molecular Machines: Single and Coupled Chemical Reactions; Cyclical Chemical Reactions and Onsager's Reciprocal Relations; Efficiency of Energy Transfer; Chemical Reactions, Mass Transport, and Molecular Machines; Autocatalytic Reactions and Diffusion; Morphogenesis. Instabilities and Pattern Formation: Linear and Non-Linear Theories of Stability; Chemical Instabilities; Spatio-Temporal Patterns in Heterogeneous Systems; Turing Structures.

# **Prerequisites**

Basic knowledge of equilibrium thermodynamics and statistical mechanics

#### **Teaching form**

Classroom lectures.

Lectures will be in Italian in the absence of Erasmus students; in English otherwise.

# Textbook and teaching resource

Georgy Lebon, David Jou, José Casas Vàzquez, *Understanding Non-equilibrium Thermodynamics: Foundations, Applications, Frontiers*, Springer-Verlag Berlin Heidelberg, 2008, http://login.proxy.unimib.it/login?url=http://dx.doi.org/10.1007/978-3-540-74252-4 Handouts

#### Semester

First year, second term

#### **Assessment method**

Oral exam on topics covered during the class lectures. The oral exam aims at verifying the level of knowledge acquired by the student, his/her understanding of the main conceptual junctures in the development of the theory presented during the class and his/her appropriate use of the natural language.

#### Office hours

By appointment

# **Sustainable Development Goals**

AFFORDABLE AND CLEAN ENERGY