



UNIVERSITÀ  
DEGLI STUDI DI MILANO-BICOCCA

## SYLLABUS DEL CORSO

### Termodinamica di Non Equilibrio

2526-1-F5402Q015

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#### 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 will 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.

### 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

24 two-hour lectures, in person, Delivered Didactics

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

## Textbook and teaching resource

Georgy Lebon, David Jou, José Casas Vázquez, *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

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