UNIVERSITÀ
DEGLI STUDI DI MILANO-BICOCCA

# COURSE SYLLABUS

## Non Equilibrium Thermodynamics

**2122-1-F5401Q068**

### Aims

The aim of the course is to provide students with a modern conceptual framework of the thermodynamics of systems out of equilibrium, not limited to near-equilibrium thermodynamics. Examples of notable applications wil be given.

**Knowledge and understanding**

- _____
- Procedures to compute non-equilibrium thermodynamic quantities
- Criteria for the evaluation of stability in out-of-equilibrium thermodynamic systems

**Applying knowledge and understanding**

- _____
- 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**

- _____
- 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 (8 hrs.)

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 (16 hrs.)

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 (4 hrs.)

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 (12 hrs.)

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 (8 hrs.)

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

## Semester

First year, second semester

## Assessment method

Oral exam.

## Office hours

By appointment