Bachelor in Physics
(Academic Year 2022-23)

Non-Equilibrium Thermodynamics			**Code**	800508	**Year**	3º	**Sem.**	2º
Module	Fundamental Physics	**Topic**	Obligatory of Fundamental Physics		**Character**	Optional		

	Total	**Theory**	**Exercises**
ECTS Credits	6	4	2
Semester hours	45	30	15

Learning Objectives (according to the Degree's Verification Document)

- Learning the thermodynamic formalism applicable to systems out of equilibrium.
- Learning to apply non-equilibrium thermodynamics to the study of processes in different physical systems.
- Learning to understand the behavior of systems very far from equilibrium.
- Understanding the limitations of thermodynamics in infinite time.

Brief description of contents

Conservation laws. Balance equations. Phenomenological equations. Onsager relationships. Stationary states. Minimum entropy production. Applications: processes in homogeneous, continuous and heterogeneous systems. Systems very far from equilibrium. Thermodynamics in finite time.

Prerequisites

Thermodynamics. Physics Laboratory II (Thermodynamics). Calculus. Tensors.

Coordinator	Juan Pedro García Villaluenga			**Dept.**	EMFTEL
	Office	117	**e-mail**	jpgarcia@ucm.es	

Theory/Exercises – Schedule and Teaching Staff

Group	**Lecture Room**	**Day**	**Time**	**Professor**	**Period/ Dates**	**Hours**	**T/E**	**Dept.**
B	4ª	Tu Th	17:00-18:30 16:30-18:00	Chantal Valeriani	Full semester	30	T	EMFTEL
				Cristina Rincon Cañibano		15	E	EMFTEL

T: Theory, E: Exercises

Office hours

Group	**Professor**	**Schedule**	**E-mail**	**Location**
B	Chantal Valeriani	M y J: 13:00-14:00	cvaleriani@ucm.es	D. 119, 1ª pl. Este
	Cristina Rincón Cañibano	V: 13:30-16:30	crrincon@ucm.es	106. 1ª Planta Módulo Este

Syllabus

1. Review of the basics of equilibrium thermodynamics

The fundamental laws. Basic equation of Thermodynamics. (Gibb's Equation) The thermodynamic potentials. Equilibrium and stability. Chemical reactions.

2. Description of the Thermodynamics formalism. Conservation laws and balance equations

Local Equilibrium hypothesis. Classical transport equation of mass, energy, momentum, electrical charge and concentration. Local formulation of the second law of thermodynamics. Entropy Flow and Entropy Production.

3. Classical Thermodynamics of irreversible processes

The linear regimen. The phenomenological equations and coefficients. Onsager reciprocal relations. Curie's Law.

4. Stationary States.

Entropy production. The theorem of minimum entropy production and its limitations.

5. Simple Processes

Entropy balance. Phenomenological equations and Onsager reciprocal relations. Heat conduction. Diffusion. Electrical conduction. Chemical Reactions.

6. Coupled Processes

Entropy balance. Phenomenological equations and Onsager reciprocal relations. Thermoelectric phenomena. Thermodiffusion. Coupled chemical reactions. Molecular motors. Electrokinetic and membrane processes.

7. Introduction to systems very far from equilibrium.

Non-linear regime. Stability in systems far from equilibrium. Bifurcations.

8. Dissipative structures

Thermo-hidrodynamics Patterns: Rayleigh-Bénard convection. Bérnard-Marangoni convection.Taylor instability. Chemical oscillations: Brusselator, Belousov-Zhabotinsky. Spatio-temporal patterns: Turing structures. Chiral simmetry.

9. Finite-time thermodynamics.

Review of the Carnot cycle. Endoreversible systems.

Bibliography

Basic:

- Kondepudi, D., Prigogine, I. Modern Thermodynamics. From Heat Engines to Dissipative Structures. (Wiley Interscience, London). 1998
- Lebon, G., Jou, D., Casas-Vázquez, J. Understanding Non-Equilibrium Thermodynamics: Foundations, Applications, Frontiers. (Springer-Verlag, Berlin). 2008
- R. Haase. Thermodynamics of Irreversible Processes, (Dover, London). 1990.

Complementary:

- De Groot, S.R., Mazur, P. Non-Equilibrium Thermodynamics. (Dover, London). 1984
- Demirel, Y. Nonequilibrium Thermodynamics. (Elsevier, Amsterdam). 2007
- Glandsdorff, P., Prigogine, I. Structure, Stability and Fluctuations. (Wiley Interscience, London). 1971 § Nicolis, G., Prigogine, I. Self-organization in nonequilibrium systems. From dissipative structures to order through fluctuations. (Wiley Interscience, New York). 1977

Online Resources

UCM's Virtual Campus.

Methodology
The following training activities will be developed: • Theory lessons where the main concepts of the subject will be explained. • Practical classes of problems and directed activities. A series of problems will be provided to students in advance of their resolution in class. • Practices of Numerical Simulation Seminars in Numerical Simulation. The days and hours are the ones indicated in this same file. The distribution of hours will be, approximately, the following: for every 4 hours of lectures, 3 hours will correspond to theoretical classes and 1 hour to practical classes

Evaluation Criteria		
Exams	**Weight:**	70%
There will be a final exam consisting of theoretical-practical questions and problems. For the realization of the exam, the class notes and theory books can be consulted, freely chosen by the student.		
Other Activities	**Weight:**	30%
The following continuous evaluation activities will be carried out: Problems and exercises delivered throughout the course, individually or in groups		
Final Mark		
The final grade will be obtained by averaging the final exam grade (70%) and the continuous assessment (30%), except: a) If the exam grade is higher than the above mentioned average, in which case the final grade will be equal to the exam grade; b) the exam grade is lower than 4 out of 10, in which case the final grade will also be equal to the exam grade. The qualification of the extraordinary call of July will be obtained following exactly the same evaluation procedure.		