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| Teacher(s)          | Papalexandris Miltiadis ;                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                           |
| Language :          | English<br>> French-friendly                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                        |
| Place of the course | Louvain-la-Neuve                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                    |
| Prerequisites       | It is expected that the students have mastered the basics of thermodynamics, as covered in the courses LMECA1855 or LPHYS1343, as well as the basics of fluid mechanics, as covered in the courses LMECA1321 or LPHY1213.                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                           |
| Main themes         | <ul style="list-style-type: none"> <li>• Elaboration of a general theoretical framework of irreversible phenomena having as starting points the kinetic theory of gases and classical thermodynamics</li> <li>• Presentation of the classical theory of Onsager-Prigogine. Presentation of more recent theories such as Rational Thermodynamics (theory of Truesdell &amp; Noll) and Extended Thermodynamics (theories of Jou &amp; Lebon and of Müller).</li> </ul>                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                |
| Learning outcomes   | <p><b>At the end of this learning unit, the student is able to :</b></p> <p>With respect to the reference AA of the programme of studies "Masters degree in Mechanical Engineering", this course contributes to the development and acquisition of the following skills</p> <ul style="list-style-type: none"> <li>• AA1.1, AA1.2, AA1.3</li> <li>• AA2.1, AA2.2, AA2.3</li> <li>• AA3.1, AA3.3</li> <li>• AA5.1, AA5.2, AA5.6</li> <li>• AA6.1, AA6.2, AA6.4, AA6.5</li> </ul> <p><b>Specific learning outcomes of the course</b></p> <ul style="list-style-type: none"> <li>• A modern approach to non-equilibrium thermodynamics.</li> <li>• Unified description of thermal, mechanical, viscous, and electromechanical processes in order to enhance the student's synthetic skills.</li> <li>• Application of theoretical results in the modelling of irreversible phenomena in fluid and solid mechanics, geophysics, etc.</li> </ul>                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                         |
| Evaluation methods  | • Exam. The exam consists of exercises. It is written, with open books and notes                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                    |
| Teaching methods    | <ul style="list-style-type: none"> <li>• Course lectures</li> <li>• Sessions of exercises</li> <li>• Lectures in the classroom with physical presence.</li> </ul>                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                   |
| Content             | <ol style="list-style-type: none"> <li>1. Summary of equilibrium thermodynamics: first thermodynamic axiom (principle of energy conservation), absolute temperature and entropy, second axiom of thermodynamics, Gibbs relation, equations of Euler &amp; Duhem, thermodynamic potentials and Legendre transformations, stability of equilibrium states, evolution principles, thermochemistry.</li> <li>2. Classical theory of irreversible thermodynamics (theory of Eckart-Onsager-Prigogine): local equilibrium, balance laws and constitutive relations, entropy production, thermodynamic fluxes and forces, Onsager-Casimir reciprocal relations. Applications: Fourier-Navier-Stokes equations for Newtonian fluids, thermodiffusion.</li> <li>3. Study of thermo-electric phenomena: Hall effect, Seebeck and Peltier effects, Nerst and Ettinghausen effects, Joule and Thomson heats.</li> <li>4. Kinetic theory of gases. Derivation of the Boltzmann equation. Collision operator. Relations between macroscopic variables and kinetic theory. H-theorem. Collision invariants, Maxwell-Boltzmann distribution and derivation of balance laws. Justification of local equilibrium hypothesis. Theory of fluctuations of Einstein. Derivation of the Onsager-Casimir reciprocal relations.</li> <li>5. Introduction to rational thermodynamics. material memory, objectivity, Clausius-Duhem inequality, material-frame indifference, constitutive relations. Application in thermo-elastic materials, comparison with the linear theory of Eckart-Onsager-Prigogine. Liu's method of Lagrange multipliers and extended theories.</li> <li>6. Stationary states: criteria for minimum of entropy production and minimum of dissipated energy. Introduction to stability theory. Rayleigh-Bénard instability.</li> </ol> |
| Inline resources    | <a href="https://moodle.uclouvain.be/course/view.php?id=818">https://moodle.uclouvain.be/course/view.php?id=818</a>                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                 |

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|-----------------------------|--------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| Bibliography                | <ul style="list-style-type: none"> <li>• G. Lebon, D. Jou &amp; J. Casas-Vasquez, <i>Understanding Non-equilibrium Thermodynamics</i> , Springer, 2008. <b>Mandatory</b>, available on the e-books of the library in electronic form.</li> <li>• D. Kondepudi &amp; I. Prigogine, <i>Modern Thermodynamics</i> , Wiley, 1999. <b>Recommended</b> .</li> <li>• S.R. De Groot and P. Mazur, <i>Non-equilibrium Thermodynamics</i> , Dover, 1984. <b>Recommended</b> .</li> </ul> |
| Faculty or entity in charge | MECA                                                                                                                                                                                                                                                                                                                                                                                                                                                                           |

| Programmes containing this learning unit (UE)  |                         |         |              |                                                                                     |
|------------------------------------------------|-------------------------|---------|--------------|-------------------------------------------------------------------------------------|
| Program title                                  | Acronym                 | Credits | Prerequisite | Learning outcomes                                                                   |
| Master [60] in Physics                         | <a href="#">PHYS2M1</a> | 5       |              |  |
| Master [120] in Mechanical Engineering         | <a href="#">MECA2M</a>  | 5       |              |  |
| Master [120] in Electro-mechanical Engineering | <a href="#">ELME2M</a>  | 5       |              |  |
| Master [120] in Mathematical Engineering       | <a href="#">MAP2M</a>   | 5       |              |  |
| Master [120] in Physics                        | <a href="#">PHYS2M</a>  | 5       |              |  |
| Master [120] in Energy Engineering             | <a href="#">NRGY2M</a>  | 5       |              |  |