PROGRAMME OF THE LECTURE **'THERMODYNAMICS'**

Department of Physical Sciences. University of Oulu. Spring term 2023

Lecturer: Antonio Ferriz Mas

THERMODYNAMICS with applications to
Astrophysics and Atmospheric Physics

1. Introduction

Thermodynamic variables. Constitutive axioms. Processes. Mechanical and heating powers.

2. First and second principles for homogeneous processes

Internal energy. First principle. Irreversibility. Entropy. Second principle. Isothermal, adiabatic and isentropic processes. Combined expression of the first and second principles in terms of Helmholtz' free energy F.

3. Constitutive relations (*'equations of state')*

Constitutive relations (for materials without memory). Thermodynamic potentials (U, H, F and G) and their *natural variables*. Compatibility conditions; Maxwell's relations.

4. Specific heats and other material coefficients

Material coefficients for simple fluids: coefficients of thermal expansion, adiabatic/isothermal compressibility, adiabatic/isothermal sound speeds, specific heats at constant pressure/volume. Chandrasekhar's coefficients Γ_1, Γ_2 and Γ_3 (*'adiabatic exponents'*). Relationships among the different material coefficients.

5. Constitutive relations: ideal gas and mixture of ideal gas and black-body radiation

Constitutive relation for the ideal gas model. Expression of the mean molar mass (or the mean mass per free particle, μ) as a function of the chemical abundancies. Ideal gas in equilibrium with black-body radiation; computation of Γ_1, Γ_2 and Γ_3.

6. Stability and phase transitions

Stability conditions and their implications for the sign of some of the material coefficients; why the ratio $\gamma = c_p/c_v$ must be > 1. First-order phase transitions.

7. Applications of thermodynamics to the atmosphere

Hydrostatic equilibrium. Simple atmospheric models. Lapse rate and vertical stability. Thermal wind equation. Jet streams.

8. Thermodynamics of self-gravitating spherical masses and an introduction to stellar structure

Obtention of the virial theorem for a self-gravitating mass distribution in hydrostatic equilibrium. Applications of the virial theorem to the stellar structure: (a) Relationship between the internal energy and the gravitational potential energy. (b) Evaluation of the mean temperature $\langle T_\star \rangle$ for a star in hydrostatic equilibrium; dependence of $\langle T_\star \rangle$ on the mean mass per free particle μ. (c) Restriction on the value of the ratio of specific heats γ for a star in hydrostatic equilibrium. (d) Quasistatic contraction and *'negative specific heat'*; the Kelvin-Helmholtz time scale. (e) Enthalpy in a self-gravitating system.

BIBLIOGRAPHY

• **1. Thermodynamics and an Introduction to Thermostatistics**, H. B. **C**allen, John Wiley & Sons (1991, 2nd Edition).
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• **2. The Fundamentals of Stellar Astrophysics**, George W. **C**ollins, W. H. Freeman & Co. (1989). ISBN-10: 0716719932, ISBN-13: 978-0716719939

• **3. Principles of Stellar Structure** (Vol. I), John P. **C**ox & R. Thomas Giuli, Gordon & Breach (1968). ASIN: B00BL8JE5W

• **4. The Physics of Atmospheres**, John **H**oughton, Cambridge University Press (2002, 3rd Edition). ISBN-10: 0521011221, ISBN-13: 978-0521011228

• **5. Rational Thermodynamics**, Clifford A. **T**ruesdell, Springer-Verlag [2^{d} edition 1984]. ISBN-10: 1461297370

• **6. The Tragicomical History of Thermodynamics, 1822-1854**, Clifford A. **T**ruesdell, [Volume 4 in the book series: 'Studies in the History of Mathematics and Physical Sciences'], Springer-Verlag (1980). ISBN: 978-1-4613-9444-0