Westlake University Undergraduate Course Syllabus

1. Course Information

Course Name	**Thermodynamics and Statistical Mechanics**		**Credits**	**4**
Class Hours	**Teaching Hours**	**Practice Hours**	**Lab Hours**	**Total**
	64			**64**
Prerequisite courses (Consistent with major roadmap）				

2. Course Coordinator

Name	**Tang Leihan**	**Contact Info**	**tangleihan@westlake.edu.cn**
Office Address	**E5-121**	**Office Hours**	

3. Course Instructor

Name #1	**Tang Leihan**	**Name #2**	
Contact Info	**tangleihan@westlake.edu.cn**	**Contact Info**	
Name #3		**Name #4**	
Contact Info		**Contact Info**	

4. Course Description（No more than 500 words）

In this course, students will gain a comprehensive understanding of the principles and tools of thermodynamics and statistical mechanics. This knowledge will enable them to analyze macroscopic properties of physical systems based on microscopic interactions. They will develop critical thinking and problem-solving skills by applying theoretical concepts and formalism to selected classical and quantum systems. While most discussions will focus on systems in thermal equilibrium, we will also touch upon dissipative processes towards equilibrium, such as particle collisions and Boltzmann's H-theorem. Examples drawn from various fields of physics will illustrate the prowess of the statistical approach in capturing emergent behavior from simple units—a concept increasingly relevant in engineering, social sciences, and biological sciences.

Students will engage in various learning methods, including lectures, tutorials, and mini-projects. Lectures are designed to elucidate core concepts, physical reasoning, and mathematical derivations, while tutorials use exercises and case studies to enhance skills in applying theory to problem-solving contexts. Assessments will consist of problem sets, projects, and midterm and final exams to evaluate students' proficiency in applying theoretical concepts and mathematical manipulations. This dynamic learning environment will prepare students to delve deeply into theoretical approaches, navigate interconnected concepts, and innovate in applying physical principles and quantitative analysis to complex problems in their future careers.

5. Learning Objectives

1. Thermodynamic principles and formalisms: identify variables that characterize a thermodynamic state; explain the four laws of thermodynamics and their role in constraining thermodynamic processes; utilize thermodynamic potentials and the equation of state for quantitative characterization of specific systems and processes.
2. Kinetic theory: apply probability theory to the treatment of particle collisions in a dilute gas of particles; solve problems involving the dynamical evolution of the particle system using statistical methods.
3. Ensemble theory: understand and apply ensemble theory to analyze thermodynamic properties of a classical system; develop problem-solving skills to calculate thermodynamic potentials and the equation of state.
4. Interacting particles systems: analyze systems of interacting particles using cumulant expansion and the variational principle; apply approximate mathematical schemes to obtain thermal properties.
5. Quantum statistical mechanics: derive thermodynamic potentials and the equation of state for indistinguishable particles under quantum statistics; apply the formalism to study degenerate Fermi gases and Bose-Einstein condensation.
6. Communication of scientific ideas: articulate scientific ideas of this course effectively, connecting theoretical concepts to physical interpretations in both written and oral forms.

6. Course Content

The course begins with revision of thermal concepts, followed by an exploration of the laws of thermodynamics, which govern the general properties of thermodynamic processes. Various thermodynamic potentials are utilized for the quantitative characterization of specific systems and processes. After reviewing basic concepts in probability theory, a statistical description is applied to the temporal evolution of a dilute gas of particles undergoing binary collisions. The ensemble theory of classical statistical mechanics is then introduced. Connetion to thermodynamics is established and the calculation of thermodynamic potentials illustrated with simple examples. Two approximate schemes, cumulant expansion and the variational principle, are used to treat systems of interacting particles and phase transitions. The final chapters focus on indistinguishable particles that obey quantum statistics, examining black-body radiation, heat capacity of polyatomic gas and solids, and properties of the degenerate Fermi gas and Bose-Einstein condensation.

7. Course Schedule

Week	**Session**	**Class Hour**	**Instructor(s)**	**Theme/Topic**	**Teaching activities（lecture /practical）**
Week 1	Lectures 1-3	3	Leihan Tang	Revision of thermal concepts, equation of state, the first law	Lecture
	Tutorial	1			Lecture
Week 2	Lectures 4-6	3	Leihan Tang	The second law, Carnot cycle, entropy, thermodynamic potentials	Lecture
	Tutorial	1			Lecture
Week 3	Lectures 7-9	3	Leihan Tang	Gibbs-Duhem and Maxwell relations, thermal stability, the third law	Lecture
	Tutorial	1			Lecture
Week 4	Lectures 10-12	3	Leihan Tang	Random variables, probability density function, moments, cumulants, generating function, joint distributions, the Central Limit Theorem, Stirling formula, information, Shannon entropy and estimation	Lecture
	Tutorial	1			Lecture
Week 5	Lectures 13-15	3	Leihan Tang	Kinetic theory, Liouville's theorem, BBGKY hierarchy, Boltzmann equation	Lecture
	Tutorial	1			Lecture
Week 6	Lectures 16-18	3	Leihan Tang	The H-theorem and irreversibility, equilibrium properties, conservation laws and transport, zeroth- and first-order hydrodynamics	Lecture
	Tutorial	1			Lecture
Week 7	Lectures 19-21	3	Leihan Tang	Microcanonical ensemble, ergodic hypothesis, Botzmann entropy, two-level systems and ideal gas, Gibbs paradox	Lecture
	Tutorial	1			Lecture

Week 8	Lectures 22-24	3	Leihan Tang	Canonical ensemble, Boltzmann distribution, partition function, free energies, thermal averages and fluctuations, examples	Lecture
	Tutorial	1			Lecture
Week 9	Lectures 25-27	3	Leihan Tang	Grand canonical ensemble, chemical potential, phase coexistence	Lecture
	Tutorial	1			Lecture
Week 10	Lectures 28-30	3	Leihan Tang	Interacting particle systems, cumulant and cluster expansions, virial equation of state, van der Waals equation of state and phase transitions	Lecture
	Tutorial	1			Lecture
Week 11	Lectures 31-33	3	Leihan Tang	Mean-field theory of condensation, variational methods, law of corresponding states, critical phenomena	Lecture
	Tutorial	1			Lecture
Week 12	Lectures 34-36	3	Leihan Tang	Quantum statistics, specific heat of polyatomic gases, vibrations of a solid, Debye theory	Lecture
	Tutorial	1			Lecture
Week 13	Lectures 37-39	3	Leihan Tang	Black-body radiation, many-particle quantum states, density matrix of mixed states in micro-canonical and canonical ensembles	Lecture
	Tutorial	1			Lecture
Week 14	Lectures 40-42	3	Leihan Tang	Ideal quantum gases, bosons and fermions, occupation number representation, Bose-Einstein and Fermi-Dirac distributions	Lecture
	Tutorial	1			Lecture
Week 15	Lectures 43-45	3	Leihan Tang	Non-relativistic gas, classical limit, degenerate Fermi gas, Fermi energy and temperature	Lecture
	Tutorial	1			Lecture

Week 16	Lectures 46-48	3	Leihan Tang	Degenerate Bose gas, Bose-Einstein condensation, superfluidity	Lecture
	Tutorial	1			Lecture

8. Assessment Weight

Type of Assessment	**Percentage of Final Score**	**Notes**
Attendance	**10%**	
Class Performance		
Quiz		
Project	**10%**	
Assignments	**30%**	
Mid-term Exam	**20%**	
Final Exam	**30%**	
Other		

9. Grading

☐A. Graded

☐ B. Pass/Fail

√ C. Hundred Point Scale

10. Textbook and Supplementary Readings

1. Mehran Kardar, *Statistical Physics of Particles*, Cambridge, 2007.
2. A. B. Pippard, *Elements of Classical Thermodynamics*, Cambridge, 1966.
3. F. Mandl, *Statistical Physics*, 2nd Ed., Wiley, 1988.
4. Shang-Keng Ma, *Statistical Mechanics*, World Scientific, 1985.
5. Michael Plischke and Birger Bergersen, *Equilibrium Statistical Physics*, 3rd Ed, World Scientific, 2006.
6. Jim Sethna, *Statistical Mechanics: Entropy, Order Parameters, and Complexity*, 2nd Ed, Oxford, 2021.
7. David L Goodstein, *States of Matter*, Dover, 2014.