Syllabus for Thermal Physics

I. Basic Information

Title	Thermal Physics	Course #	PHYS3102
Category	Major Basic	Audience	Physics (normal) - International class
Credits	3	Hours	36
Instructor	SHI, Ziliang (石子亮)	Revised	Oct. 08, 2021
Textbook	Hugh D. Young and Roger A. Freedman, *Sears and Zemansky's University Physics with Modern Physics (12th Edition)*，Pearson Education, Inc. and China Machine Press，2011		

II. Goals and Objectives

A. Overall goals

Thermal Physics is a branch of physics that deals with heat, work, and energy possessed by matter. The course aims to provide students with: 1) Concepts of thermodynamics and basic statistical physics; 2) Methods of studying thermodynamic properties from both macroscopic thermodynamics laws and microscopic kinetic theories; 3) Links between the microscopic properties of individual atoms/molecules and the macroscopic properties of system formed from the atoms/molecules; 4) Applications of thermodynamics concepts to a variety of systems such as gases, engines and even human body; 5) Mathematical derivations of the fundamental thermodynamic relations.

The course is a prerequisite to *Statistical Physics*, which applies statistical methods to explain and predict the thermodynamic properties of a system.

B. Objectives

Objective 1：In the chapters relating to the topics such as kinetic theory of gas , heat engines, and the second law of thermodynamics, stories of scientists and engineers of the older generation in developing theories and technologies will be shared. Their great efforts, devotions, and perseverance will stimulate the students' enthusiasm for learning science and encourage them to serve our country.

Objective 2：*Thermal Physics* is one of the first two courses of physics, by which the students should not only learn the knowledge of physics and feel the power of math tools, but also learn the methodology of physics, including observations, designed experiments, idealized models and assumptions, theory and analyze, etc. Such trainings set up a foundation for their future study and research.

Objective 3：Show, as many as possible, examples that are closely related to daily life, so that, the students can learn how to use the knowledge of thermodynamics to solve practical problems. Also, each student is asked to find and analyze an actual thermal phenomenon by himself and show the results in an oral presentation. To develop the habit of self-education, the students are asked to preview the context before class and moreover to study a few of sections (including thermal expansion, heat transfer and refrigerator) by themselves.

Objective 4: By discussions of the fundamental concepts, such as temperature, the first law of thermodynamics and entropy, students are guided to think about the fundamentals of our universe and to feel the art of logic and reasoning. These deep discussions could motivate their interests in science and pursuit of truth. All-English teaching would improve their ability in communicating internationally and reading the scientific materials in English.

C. Correlations—Objectives, graduation requirements, teaching contents

Table 1: Correlations between course objectives, graduation requirements and teaching contents

Objectives	**Teaching contents**	**Graduation requirements**
Objective 1	Contents of all chapters. Examples include Chapter 17 Introduction (China's contribution in thermodynamics and statistical physics), Chapter 18-20 Stories of scientists in developing theories of thermal physics.	Requirements 3
Objective 2	Contents of All chapters, including Introduction of Calculus, Probability theory and other prerequisite math tools.	Requirements 2-1 to 2-3, 3
Objective 3	Contents of All chapters, in which "Section 17.4 Thermal Expansion", "Section 17.7 Mechanisms of Heat Transfer" and "Section 20.4 Refrigerators" are for self-taught.	Requirements 2-1 to 2-3, 7, 8
Objective 4	Contents of All chapters, including deep discussions on the concepts of temperature, equation of state, probability and entropy.	Requirements 2-1 to 2-3, 5, 7, 8

III. Teaching Contents

Chapter 17 Temperature and Heat (Sears' book)

1. Teaching Objectives:

Learn basic concepts of physics, thermal physics

2. Focus and/or Dificulties

Find relations of Physics and other sciences; understand the concept of temperature, the thermal system and the concept of heat and phase of matters.

3. Main Contents:

The first unit: Temperature and Thermal Equilibrium

The meaning of thermal equilibrium; What do thermometers really measure.

The second unit: Thermometers and Temperature Scales

How different types of thermometers function.

The third unit: Gas Thermometers and the Kelvin Scale

The physics behind the absolute, or Kelvin, temperature scale.

The forth unit: Quantity of Heat

The meaning of heat, and how it differs from temperature.

The fifth unit: Calorimetry and Phase Changes

How to do calculations that involve heat flow, temperature changes, and changes of phase.

The sixth unit: Mechanisms of Heat Transfer

How heat is transferred by conduction, convection, and radiation.

The seventh unit: Phase of Matter

What determines whether a substance is a gas, a liquid, or a solid.

Chapter 18 Thermal properties of matter (Sears' book)

1. Teaching Objectives:

Learn the description of a gas in a microscopic viewpoint.

2. Focus and/or Dificulties

Understand the Kinetic-Molecular Model of a gas; the use of Newton's mechanics to explain macroscopic variables of a gas.

3. Main Contents:

The first unit: Equations of State

How to relate the pressure, volume, and temperature of a gas.

The second unit: Molecular Properties of Matter

How the interactions between the molecules of a substance determine the properties of the substance.

The third unit: Kinetic-Molecular Model of an Ideal Gas

How the pressure and temperature of a gas are related to the kinetic energy of its molecules.

The forth unit: Heat Capacities

How the heat capacities of a gas reveal whether its molecules are rotating or vibrating, and the derivation of heat capacity equations.

The fifth unit: Molecular Speeds and Speed Distribution

The physical meaning of the speed distribution function; Lean to derive the three speeds: average speed, RMS speed, and most probable speed.

The sixth unit: Transportation Properties of Gases (Blundell's Book)

Understand the macroscopic rules and the microscopic interpretation of the transport processes.

Chapter 19 The 1st law of Thermodynamics (Sears' book)

1. Teaching Objectives:

Learn the 1^{st} law of thermodynamics.

2. Focus and/or Dificulties

Understand the mechanism of energy conservation; Use the 1^{st} law to calculate heat/work/internal energy change in thermal processes.

3. Main Contents:

The first unit: Thermodynamic Systems

How to represent heat transfer and work done in a thermodynamic process.

The second unit: Work Done During Volume Changes

How to calculate the work done by a thermodynamic system when its volume changes.

The third unit: Paths Between Thermodynamic States

What is meant by a path between thermodynamic states.

The forth unit: Internal Energy and the First Law of Thermodynamics

How to use the first law of thermodynamics to relate heat transfer, work done, and internal energy change.

The fifth unit: Kinds of Thermodynamic Processes

How to distinguish among adiabatic, isochoric, isobaric, and isothermal processes.

The sixth unit: Internal Energy of an Ideal Gas

How we know that the internal energy of an ideal gas depends only on its temperature.

The seventh unit: Heat Capacities of an Ideal Gas

The difference between molar heat capacities at constant volume and at constant pressure.

How to use these quantities in calculations.

The eighth unit: Adiabatic Processes for an Ideal Gas

How to analyze adiabatic processes in an ideal gas.

Chapter 20: The 2nd law of Thermodynamics (Sears' book)

1. Teaching Objectives:

Learn the 2^{nd} law, the concept of entropy and basic of statistical physics.

2. Focus and/or Dificulties

Understand the working mechanism of heat engines; Use both the 1st and 2nd law to calculate heat/work/internal energy/entropy/enthalpy change in thermal processes.

3. Main Contents:

The first unit: Directions of Thermodynamic Processes

What determines whether a thermodynamic process is reversible or irreversible.

The second unit: Heat Engines

What a heat engine is; How to calculate its efficiency.

The third unit: Internal-Combustion Engines

The physics of internal-combustion engines.

The forth unit: Refrigerators

How refrigerators and heat engines are related; How to analyze the performance of a refrigerator.

The fifth unit: The Second Law of Thermodynamics

How the second law of thermodynamics sets limits on the efficiency of engines and the performance of refrigerators.

The sixth unit: The Carnot Cycle

How to do calculations involving the idealized Carnot cycle for engines and refrigerators.

The seventh unit: Entropy

What is meant by entropy, and how to use this concept to analyze thermodynamic processes.

The eighth unit: Microscopic Interpretation of Entropy

Understand the Microscopic Interpretation of Entropy.

Additional Section: Phase transitions (Chapter 28 of Blundell's Book)

1. Teaching Objectives:

Learn the concept of phase of matters.

2. Focus and/or Dificulties

Understand the mechanism of phase transitions; Use thermodynamic laws to calculate macroscopic variables change in phase transitions.

3. Main Contents:

The first unit: Latent Heat (Review)

Calculations of heat involving the latent heat in phase transition.

The second unit: Chemical Potential and Phase Changes

Master the characteristics of gas-liquid phase transition.

The third unit: The Clausius－Clapeyron equation

The derivation of the Clausius－Clapeyron equation, and its applications to phase transtion.

IV. Teaching Hours

Table 2: Chapters and teaching hours

Chapters	Contents	Hours
Chapter 17	Temperature and Heat	6
Chapter 18	Thermal Properties of Matters	6
Chapter 19	The First Law of Thermodynamics	6
Chapter 20	The Second Law of Thermodynamics	6
Additional Section	Phase Transitions	3

V. Teaching Schedule

Table 3: Schedule

Lecture	Contents	Hours	Learning Goals and Requirements	Notes
1	Introduction, Temperature and Thermal Equilibrium, Thermometers and Temperature Scales, Gas Thermometers and the Kelvin Scale	3	The meaning of thermal equilibrium, and what thermometers really measure. How different types of thermometers function. The physics behind the absolute, or Kelvin, temperature scale.	Introduction, Concepts, Temperature, Temperature Scales, Thermometers

2	Quantity of Heat, Calorimetry and Phase Changes, Phase of Matter. -Quiz ONE-	3	The meaning of heat, and how it differs from temperature. How to do calculations that involve heat flow, temperature changes, and changes of phase. What determines whether a substance is a gas, a liquid, or a solid.	Heat, Phase Changes, Heat Transfer, Phase of Matter. Quiz.
3	Equations of State, Molecular Properties of Matter, Ideal gas equation. Gas mixture. Non-ideal gas.	3	How to relate the pressure, volume, and temperature of a gas. Ideal gas equation. Gas mixture: Partial pressure equation. Non-ideal gas. How the interactions between the molecules of a substance determine the properties of the substance. Analysis of Quiz 1 and homework. Answer students' questions.	Equations of State, Intermolecular Force, Gas mixture.
4	Kinetic-Molecular Model of an Ideal Gas, Microscopic Interpretation of Temperature, Pressure. -Quiz TWO-	3	Learn how to derive the pressure equation. How the temperature of a gas are related to the kinetic energy of its molecules. Understand the relation between microscopic molecular motions and macroscopic properties such as pressure and temperature.	Derive pressure equation. Microscopic view of temperature. Quiz.
5	Molecular collisions. Basic knowledge on probability. Molecular Speeds, Speed Distribution. Heat Capacities of Gases.	3	Molecular collisions and mean free path. Master the physical meaning of the velocity distribution function and its related form. How the heat capacities of a gas reveal whether its molecules are rotating or vibrating. Analysis of Quiz 2 and homework. Answer students' questions.	Equipartition of Energy and Degrees of Freedom are the key points.

6	Thermodynamic Systems, Work Done During Volume Changes, Paths Between Thermodynamic States, Internal Energy and the First Law of Thermodynamics.	3	How to represent heat transfer and work done in a thermodynamic process. How to calculate the work done by a thermodynamic system when its volume changes. What is meant by a path between thermodynamic states. How to use the first law of thermodynamics to relate heat transfer, work done, and internal energy change.	Use examples to show the application of the first law of thermodynamic s
7	Kinds of Thermodynamic Processes, Internal Energy of an Ideal Gas. -Quiz THREE-	3	How to distinguish among adiabatic, isochoric, isobaric, and isothermal processes. How do we know that the internal energy of an ideal gas depends only on its temperature.	Four Thermodynami c Processes, and related Heat, Work and Internal Energy Calculations. Quiz.
8	Heat Capacities of an Ideal Gas, Adiabatic Processes for an Ideal Gas.	3	The difference between molar heat capacities at constant volume and at constant pressure, and how to use these quantities in calculations. How to analyze adiabatic processes in an ideal gas. Analysis of Quiz 4 and homework. Answer the students' questions.	Two types of heat capacity and related calculations. adiabatic processes is important for analyzing Engine in the following lectures
9	Directions of Thermodynamic Processes, Heat Engines, Internal-Combustion Engines, Refrigerators, The Second Law of Thermodynamics. -Quiz FOUR-	3	What determines whether a thermodynamic process is reversible or irreversible. What a heat engine is, and how to calculate its efficiency. The physics of internal-combustion engines. How refrigerators and heat engines are related. How the second law of thermodynamics sets limits on the engines and the refrigerators.	Reversible or Irreversible Thermodynami c Processes, Engines, The 2nd Law and Engine Efficiency. Quiz.
10	The Carnot Cycle, Entropy, Microscopic Interpretation of Entropy.	3	How to do calculations involving the idealized Carnot cycle for engines and refrigerators. What is meant by entropy, and how to use this concept to analyze thermodynamic processes. Analysis of Quizs 4 and homework. Answer the students' questions.	Carnot Cycle, Entropy.

11	Latent Heat, Chemical Potential and Phase Changes, The Clausius–Clapeyron Equation. -Quiz FIVE-	3	How to calculate process involving the latent heat in the phase transition. Master the characteristics of gas-liquid phase transition. Master the Clausius–Clapeyron equation and its applications.	Latent Heat, The Clausius–Clapeyron Equation. Quiz.
12	Introductions to Demonstrations, Student Presentations and Thermal Physics Projects/Demonstrations.	3	Students present their projects, lecturer comments on the presentation and demonstration.	Student presentations and demonstrations.
13	Final Review.	3	Review all chapters. Analysis of Quiz 5 and homework. Answer the students' questions.	Final Review and discussion.

VI. References

1. H. D Young and R. A. Freedman, *Sear and Zemansky's University Physics with Modern Physics*, 12th Edition, Pearson Education, 2008 (chapter 17 - 20).
2. S. J. Blundell and K. M. Blundell, *Concepts in Thermal Physics*, 2nd edition, Oxford University Press, 2009 (chapter 1 - 18).
3. Dexin Lu, *University Physics*, Higher Education Press, 2003.
4. 李椿，章立源，钱尚武，《热学》（第三版），高等教育出版社，2015.

VII. Teaching method

1. Lecture. PPT plus writing on the blackboard. Outlines, examples, schematic pictures and cartoon or movies are shown by PPT, while derivations and solutions are performed on the blackboard. Examples are selected from the above listed reference books and the internet resources.

2. Presentation by students. Each student needs to give an oral presentation on an assigned topic. Their performances are scored.

3. Preview. All students are asked to preview the context before class.

4. Self-education. Students need to study Sections *17.4 Thermal Expansion*, *17.7 Mechanisms of Heat Transfer* and *20.4 Refrigerators* by themselves.

VIII. Assessment and Grading

A. Correlations between assessment and course objectives

Table 4: Correlations between assessment and course objectives

Objectives	Assessment points	Way of assessment
Objective 1	All teaching contents	Performance + Quiz + Final Exam
Objective 2	All teaching contents	Performance + Quiz + Final Exam
Objective 3	All teaching contents	Performance + Quiz + Final Exam
Objective 4	All teaching contents	Performance + Quiz + Final Exam

B. Grading

1．Grading Scheme

Performance 30% (including Attendance 5%, Presentation 5% and Homework 20%); Quiz 30%; Final Exam 40%.

2．Percentages in the assessment and Degrees of accomplishment of the objectives

Table 5: Percentages in the assessment and Degrees of accomplishment of the objectives

Percentages / Objectives	Performance	Quiz	Final Exam	Degree of accomplishment

Objective 1	30%	30%	40%	Performance + Quiz + Final Exam
Objective 2				
Objective 3				
Objective 4				

C. Standards

Objectives	**Standards**				
	90-100	**80-89**	**70-79**	**60-69**	**＜60**
	优	良	中	合格	不合格
	A	**B**	**C**	**D**	**F**
Objective 1	Performance + Quiz + Final Exam				
Objective 2					
Objective 3					
Objective 4					