

ME EN 5960-6960 Nanoscale Heat Transfer

Department of Mechanical Engineering University of Utah Fall 2013

Instructor:	Prof. Mathieu Francoeur Office: 2126 MEB Phone: 801-581-5721 Email: <u>mfrancoeur@mech.utah.edu</u>					
Office Hours:	By appointment via email					
Class Schedule:	T,H 12:25 pm – 1:45 pm WEB 2470					
Required Textbook:	Z.M. Zhang, Nano/Microscale Heat Transfer, McGraw-Hill, 2007.					
Other Textbook:	G. Chen, Nanoscale Energy Transport and Conversion, Oxford, 2005.					
Course Summary:	Traditional macroscale thermal science is based on classical equilibrium and continuum assumptions. These assumptions break down at the molecular and atomic length scales, and the classical theories, such as Fourier's law for heat conduction or Planck's blackbody distribution for radiation, are no longer applicable at micro/nanoscale. With the major progress over the past two decades in controlling matter at the nanoscale, nanotechnology is becoming an integral part of almost all engineering disciplines. This course will provide a self- contained overview of thermal transport and thermophysical properties at the nanoscale, and will introduce the elements of quantum mechanics, solid state physics, statistical thermodynamics and fluctuational electrodynamics necessary to understand these phenomena.					
Prerequisites:	ME EN 3650: Heat Transfer (or equivalent)					
Grading:	<u>Final Composite Score Based On:</u> Mid-term exam 1 (take-home) Mid-term exam 2 (take home) Final quiz (in class) Homework Project	Undergraduate 25% 25% 10% 40% <u>N/A</u> 100%	Graduate 25% 25% 10% 30% <u>10%</u> 100%			
Grading Scale:	93 - 100%: A 90 - 92%: A- 87 - 89%: B+ 83 - 86%: B 80 - 82%: B- 77 - 79%: C+					

73 – 76%:	С
70 – 72%:	C-
67 – 69%:	D+
63 – 66%:	D
60 – 62%:	D-
below 60%:	Е

Final grading scale may be lowered by the instructor based on the overall class performance, but will not be raised.

- **Exams:** Two mid-term exams (take-home) and a final quiz (in class) are scheduled. The final quiz will be comprehensive. In the event of a missed exam/quiz, students will be required to provide a valid explanation for the conflict and will be required to complete a make-up exam/quiz. Please notify the instructor as soon as possible if you are unable to take an exam at the scheduled time.
- **Project:** Graduate students are required to work on a research project related to Nanoscale Heat Transfer. Students are allowed to choose their own project following their research interests, subject to approval of the instructor. At the end of the semester, the student will submit a report consisting of a critical literature review of the chosen topic. The student should be able to identify the researchers in the field of interest, understand the scientific literature, and summarize it in a comprehensive document (including associated physical and mathematical modeling if applicable). The report should be made as professional as possible. At the end of the semester, the student will give a 10-15 minute oral presentation.
- Homework:
 i) In general, homework problems will be assigned on a bi-weekly basis.
 ii) Homework will be collected at the beginning of the class period when due.
 iii) No late homework will be accepted, unless the student has a valid reason.
 iv) Homework solutions will be made available on the CANVAS course site.
- Class Policies:i) All work submitted for grading should represent your individual effort. Since
engineering is a group activity, students are highly encouraged to help each other
to learn the course material and to discuss the homework assignments. However,
all homework submitted <u>must be each student's personal work</u>. Students
submitting work showing evidence of copying will receive zero credit.

ii) Submitting work copied from others will be considered academic misconduct. Plagiarism of ideas or work as well as giving or receiving unauthorized information on examinations will be considered academic misconduct. All academic misconduct will be dealt with severely and may result in a course grade of E.

iii) Laptop computers may only be used to take notes. The use of cell phones is strictly prohibited in the classroom.

iv) During the lectures, students are expected and encouraged to ask questions and participate in discussions. However, it may happen that some individuals have different points of view. While such an interactive and animated environment is usually beneficial from a learning standpoint, any disrespectful behavior toward the instructor or a classmate will not be tolerated. Any student showing such disrespectful behavior will be asked to leave the classroom.

Class Attendance: i) It is your decision whether or not to attend class.

ii) If you have a University athletic or academic activity or a business engagement, please contact the instructor before you leave to determine appropriate accommodations for the absence.

iii) If you are absent for any other reason, please contact your classmates for any pertinent material. Do not see the instructor for notes and handouts.

Class Website:
i) A CANVAS course website has been established. Syllabus, PowerPoint presentations, homework assignments, homework solutions and other useful documentation will be posted at the course website.
ii) Electronic communication with all students will be made using a class email list compiled by the registrar. CANVAS email will not be supported. If your email address listed with the registrar is out of date, please update it by accessing the Campus Information System (CIS).

Course Objectives: At the end of this course, the student will:

- 1. Understand the limits of macroscopic heat transfer based on continuum and classical equilibrium assumptions
- 2. Be knowledgeable of the Maxwell-Boltzmann, Bose-Einstein and Fermi-Dirac statistics
- 3. Understand the concept of energy quantization
- 4. Be able to describe the classical transport coefficients via the kinetic theory
- 5. Be able to formulate the Boltzmann transport equation
- 6. Be able to identify the appropriate equations for solving heat conduction problems at prescribed length and time scales
- 7. Understand the Maxwell equations and electromagnetic wave propagation
- 8. Understand the concepts of total internal reflection, evanescent waves and surface polaritons
- 9. Understand fluctuational electrodynamics applied to thermal radiation emission and be able to apply the fluctuation-dissipation theorem
- 10. Be able to solve near-field thermal radiation problems in planar geometry
- 11. Be able to formulate near-field thermal radiation problems in 3D complex geometries

Homework Guidelines:

Points to keep in mind as you prepare your homework:

- 1. Use brief comments to make your thinking clear, to connect parts of the problem, and to indicate where data and equations were obtained.
- 2. Be sure units are correct, consistent, and clearly stated.
- 3. Clearly identify the answer (box, arrow, etc.)
- 4. Use only one side of the paper.
- 5. If more than 1 problem is on a page, separate with a double line.
- 6. Number pages in lower right hand corner.
- 7. Staple at upper left hand corner.

Americans with Disabilities Act of 1990:

The University of Utah seeks to provide equal access to its programs, services and activities for people with disabilities. If you will need accommodations in the class, reasonable prior notice needs to be given to the Center for Disability Services, 162 Olpin Union Building, 581-5020 (V/TDD). CDS will work with you and the instructor to make arrangements for accommodations. All written information in this course can be made available in alternative format with prior notification to the Center for Disability Services.

Topics to be Covered^{*} (subject to change)

Topic 1: Introduction and Review of Macroscopic Thermal Sciences (Chapters 1 and 2)

A. Introduction

- B. Review of thermodynamics
- C. Review of heat transfer
- D. Overview of heat carriers

Topic 2: Elements of Statistical Thermodynamics and Quantum Theory (Chapter 3)

- A. Introduction
- B. Complex variables and basic wave characteristics
- C. Basic quantum mechanics
- D. Statistical mechanics of independent particles
- E. Thermodynamic relations
- F. Ideal molecular gases
- G. Emission and absorption of photons by molecules or atoms

Topic 3: Kinetic Theory (Chapter 4)

- A. Introduction
- B. Simple kinetic theory of ideal molecular gases
- C. The Boltzmann transport equation (BTE)
- D. Micro/nanofluidics and heat transfer

Topic 4: Thermal Properties of Solids and the Size Effect (Chapter 5)

- A. Specific heat of solids
- B. Quantum size effect on the specific heat
- C. Electrical and thermal conductivities of solids
- D. Thermoelectricity
- E. Classical size effect on conductivities

Topic 5: Non-Equilibrium Energy Transfer in Nanostructures (Chapter 7)

- A. Introduction
- B. Overview of phenomenological theories
- C. Conduction heat transfer across layered structures
- D. Heat conduction regimes

Topic 6: Fundamentals of Thermal Radiation and Energy Transfer by Electromagnetic Waves (Chapter 8)

- A. Introduction
- B. Blackbody radiation
- C. Electromagnetic waves
- D. Dielectric function
- E. Evanescent waves
- F. Radiative properties of semi-infinite media

Topic 7: Near-Field Thermal Radiation (Chapter 10)

- A. Thermal emission
- B. Tunneling of evanescent waves
- C. Near-field radiative heat transfer between semi-infinite media
- D. Dispersion relations and surface polaritons
- E. Near-field radiative heat transfer in complex geometries

* The specific sections to read in the textbook will be provided in the class notes

Week	Class #	Date	Day	Topics
1	1	Aug. 27	Т	Syllabus, Topic 1
	2	Aug. 29	Н	Topic 1
2	3	Sep. 3	Т	Topic 1
2	4	Sep. 5	Н	Topic 2
3	5	Sep. 10	Т	Topic 2
	6	Sep. 12	Н	Topic 2
4	7	Sep. 17	Т	Topic 2
	8	Sep. 19	Н	Topic 2
5	9	Sep. 24	Т	Topic 2
	10	Sep. 26	Н	Topic 3
6	11	Oct. 1	Т	Topic 3
	12	Oct. 3	Н	Topic 3
7	13	Oct. 8	Т	Topic 3
	14	Oct. 10	Н	Topic 4, Mid-Term Exam 1 due (no later than Oct. 11, 5 pm)
8		Oct. 15	Т	Fall Break
		Oct. 17	Н	Fall Break
0	15	Oct. 22	Т	Topic 4
9	16	Oct. 24	Н	Topic 4
10	17	Oct. 29	Т	Topic 4
10	18	Oct. 31	Н	Topic 4
11	19	Nov. 5	Т	Topic 5
11	20	Nov. 7	Н	Topic 5
10	21	Nov. 12	Т	Topic 6
12	22	Nov. 14	Н	Topic 6
13	23	Nov. 19	Т	Topic 6
	24	Nov. 21	Н	Topic 6
14	25	Nov. 26	Т	Topic 7
14	26	Nov. 28	Н	Thanksgiving Holiday
15	27	Dec. 3	Т	Topic 7
	28	Dec. 5	Н	Topic 7
16	29	Dec. 10	Т	Topic 7
	30	Dec. 12	Н	Final Quiz
17	31	Dec. 18	W	Oral Presentations (10:30 am – 12:30 pm)
				Mid-Term Exam 2 due (no later than Dec. 18, 5 pm)

ME EN 5960-6960 Nanoscale Heat Transfer Fall 2013 Schedule (tentative)