UNIVERSITY OF ILLINOIS AT URBANA-CHAMPAIGN
DEPARTMENT OF MECHANICAL SCIENCE AND ENGINEERING

ME 420: INTERMEDIATE HEAT AND MASS TRANSFER
COURSE INFORMATION

I. CREDIT AND CONTENT

ME 420 is a 4 credit graduate level subject serving as the Mechanical Science and Engineering department's core graduate course in heat and mass transfer. This course is open to students from all areas of engineering, although an undergraduate background in heat transfer will be assumed. This class is an appropriate preparation for the heat transfer doctoral qualifying exam.

Topics to be covered include: diffusion kinetics, conservation laws, heat conduction, laminar and turbulent convection, condensation, boiling, basic thermal radiation, and mass transfer including phase change or heterogeneous reactions. Problems and examples will include theory and applications drawn from a spectrum of engineering design and manufacturing problems.

II. CLASSES

Lectures: Twice a week for 1 hour and 50 minutes each.

Tutorials: None

Lecturer: Professor N. Miljkovic, nmiljkov@illinois.edu, MEL 2136, 617-981-9247

T.A.: None

Office Hours: T.B.A.

Textbook: Heat Transfer (2nd Edition) by A.F. Mills (Prentice Hall, 1998)

III. EXAMS AND GRADING

The course grade will be based on two midterm exams (25% each) and a final exam (50%). The tests will be open book unless otherwise announced.

Homework Problems:

A set of ten homework problems will be assigned during the course. You should work all of these problems carefully as they are essential aid to learning the material. The problems are written at a higher level of difficulty in order to prepare you for the quizzes and final. The higher difficulty of the homework is also why it is not graded. In general, if you complete the majority of the homeworks and understand the solutions, you will do great in the class.

IV. PREREQUISITES

Students entering this course should have had undergraduate classes in heat transfer, thermodynamics, and fluid mechanics. A graduate level background in mathematics will be assumed. Some specific areas you should have seen previously include:

Mathematics: Vector calculus, first and second-order ODEs, linear PDEs solved *via* separation of variables and Fourier series.
Heat Transfer: One-dimensional steady and unsteady heat conduction, fins, elementary laminar and turbulent convection, natural convection and condensation, heat exchangers, simple blackbody and gray body radiation.
Fluid Mechanics: Elementary viscous flow including Couette flow, boundary layers and tube flows, transition Reynolds number and concepts of turbulence; skin friction and pressure drop calculations.
Thermodynamics: Concept of an equation of state; first law, phase transitions.

Note however that if you have gaps in these areas, it shouldn't prevent you from doing well in this class.

V. COURSE GOAL

The goal of the course is to introduce you to graduate material in heat and mass transfer, and to aid your transition from undergraduate work into advanced graduate courses on heat transfer, energy sciences, and fluid mechanics.

VI. COLLABORATION

You may collaborate on the optional homeworks. You may not collaborate on the quizzes and final exam.

VII. LEARNING STRATEGY

To learn the material effectively, you will need attend lectures, participate in class, and ask questions when confused. Staying engaged in class is key to doing well. Also, the homework problems will prepare you above and beyond for the quizzes and final exam.

VIII. LECTURE SCHEDULE

Lecture #	Date	Topics	Readings
1		**Introduction and Conservation Equations**	Mills: 5.7 Lienhard: 2.1, 7.3 White: 1.3-1.4, Ch. 2
2		**Gas Kinetics:** Deriving Pressure, Temperature, and Mean Free Path	V & K: Ch. 1, 2
3		**Gas Kinetics:** Maxwellian Velocity Distribution, Rarefied Gas Flows	
4		**Conduction:** Steady 1-D in Slabs, Cylinders, and Spheres, Thermal Resistance, Critical Thickness of Insulation, Internal Heat Generation	Mills: 2.4.4, 3.1-3.5 Lienhard: Ch. 5
5		**Conduction:** Steady 1-D, Variable Thermal Conductivity, Conduction in General Orthogonal Coordinate Systems	
6		**Conduction:** Quasi 1-D, Composite Walls, Extended Surfaces (Fins), Moving Fins, Fins with Heat Generation, Lumped Capacitance	
7		**Conduction:** Transient 2-D, Contact of 2 Semi-Infinite Solids, Transient Heat Conduction in Finite Bodies	
8		**Conduction:** Steady 3-D, Tabular Solutions	
9		**Laminar Boundary Layers:** The Fluids Problem, D'Alembert's Paradox	Mills: 4.2, 4.3.2. 5.4, 5.8.1 Lienhard: 7.1-7.5 White: 3.5, 3.8, 4.1-4.3, 4.10-4.10.1, 4.12, 7.1-7.3 K & C: Ch. 8, 10
10		**Laminar Boundary Layers:** The Heat Transfer Problem	
11		**Laminar Boundary Layers:** The Von Karman Momentum Integral and Energy Integral Techniques	
☹		**Quiz 1**	
12		**Laminar Internal Flows**	Mills: 4.3.1, 5.3 Lienhard: 8.1-8.2 White: 3.1-3.4, 4.9 K & C: Ch. 7, 9
13		**Laminar Internal Flows and Heat Exchangers:** The LMTD and ε-NTU Methods	
14		**Heat Exchangers:** The LMTD and ε-NTU Methods	

15		**Natural Convection**	Mills: 4.4, 5.4.5, 5.8.1 Lienhard: 9.1-9.4 Bejan: Ch. 4
16		**Natural Convection**	
17		**Turbulent Boundary Layers:** The Fluids Problem	Mills: 5.5 White: 6.1-6.7, 6.10 K & C: Ch. 5, 11-14
18		**Turbulent Boundary Layers:** The Heat Transfer Problem, Flow over a Flat Plate	
19		**Turbulent Boundary Layers:** Flow Over Cylinders and Spheres, Stokes Flow	
20		**Condensation:** Laminar Filmwise on a Smooth Plate (The Nusselt Model)	Mills 7.2 Lienhard: 9.5
☹		**Quiz 2**	
21		**Condensation:** Transitional and Turbulent Filmwise on a Smooth Plate, Laminar Filmwise on Arbitrarily Shaped Surfaces	
22		**Condensation:** Dropwise	
23		**Boiling:** Bubble Growth and Departure, Nucleate Pool Boiling, The Mikic-Rohsenow Model	Mills 7.4 Lienhard: 10.1-10.4
24		**Boiling:** Critical Heat Flux, Leidenfrost Point, Film Boiling, and Homogeneous Boiling	
☺		**Thanksgiving Vacation**	
☺		**Thanksgiving Vacation**	
25		**Radiation:** Classical (Rayleigh-Jeans) and Quantum (Planck) Theories	Mills: Ch. 6 Lienhard: Ch. 11 Edwards: Ch. 1-3
26		**Radiation:** View Factors and Blackbody Exchange, Adiabatic Surfaces	
27		**Radiation:** Gray Body Enclosures, Radiation Shields,	
28		**Radiation:** Multimode Heat Transfer, Solar-Thermal Collectors	
29		**Mass Transfer**	
☹		**December Final Exam (time and place to be announced)**	

VII. REFERENCE MATERIALS

Heat Transfer, A. F. Mills, 1998 (Prentice Hall). TJ260.M52

Heat and Mass Transfer, A. F. Mills, 1995 (R.D. Irwin, Boston). TJ260.M517

A Heat Transfer Textbook, J. H. Lienhard, 2nd edition, 1987 (Prentice Hall, Englewood Cliffs). TJ260.L445

Introduction to Physical Gas Dynamics, Vincenti & Kruger, (Kiley & Sons). QC168.V775

Viscous Fluid Flow, F.M. White, 2nd edition, 1991 (McGraw Hill, NYC). QA929.W48

Convective Heat and Mass Transfer, W.M. Kays and M.E. Crawford, 3rd edition, 1993 (McGraw Hill, NYC). QC327.K37

Convective Heat Transfer, A. Bejan, 1984 (John Wiley & Sons). QC327.B48

Radiation Heat Transfer Notes, D.K. Edwards, 1981 (Hemisphere: Washington). TJ260.E318

Conduction Heat Transfer, V.S. Arpaci, Abridged Edition, 1991 (Ginn Press, Nedham Heights, MA). TJ260.A772

VIII. PHYSCIAL PROPERTIES AND UNITS

Useful Physical Constant for ME 420

Stefan-Boltzmann constant, σ	5.6697×10^{-8} W/m^{2}K^4
Ideal gas constant, R^o	8314.3 J/kmol·K
Boltzmann constant, k_B	1.38×10^{-23} J/K
Avogadro's number, N_A	6.022×10^{26} molecules/kmol

Properties of selected fluids at 20°C = 293K and 1 bar = 10^5 N/m^2

Fluid	Density ρ (kg/m^3)	Viscosity μ (kg/m s)	Thermal conductivity k (W/m K)	Coefficient of thermal expansion β (K^{-1})	Isothermal Compressibility κ_T (m^2/N)	Specific heat at constant pressure c_p (J/kgK)
Helium	0.164*	1.92×10^{-5}	0.150	3.41×10^{-3} *	1.00×10^{-5} *	5.21×10^{3} *
Air	1.19*	1.98×10^{-5}	0.0262	3.41×10^{-3} *	1.00×10^{-5} *	1.00×10^{3} *
Water	1.00×10^{3}	1.00×10^{-3}	0.597	1.8×10^{-4}	4.6×10^{-10}	4.18×10^{3}
Glycerin ($C_3H_8O_3$)	1.26×10^{3}	1.49	0.286	5.0×10^{-4}	3.7×10^{-10}	2.39×10^{3}
Mercury	1.36×10^{4}	1.55×10^{-3}	8.69	1.82×10^{-4}	0.40×10^{-10}	1.39×10^{2}

* Calculated from ideal gas relationships.

The isothermal compressibility κ_T and the coefficient of thermal expansion β are defined by the equation

$$\frac{d\rho}{\rho} = \kappa_T dp - \beta dT \ .$$

Surface tension at a clean air-water interface at 20°C : σ = 0.073 N/m