ME 539 (AP 639) *Heat Transfer Physics*, Tu & Th, 1:30-2:50 PM, Winter 2023, 3433 EECS

Department of Mechanical Engineering, University of Michigan

Week Of	Subject	Readings (Chapter. Section)	Homework, Computer Codes, and Case Studies
January 2	**Introduction and Preliminaries**: Macroscopic Energy Equation and Role of Microscale (Atomic-Level) Heat Carriers: Electron, Phonon, Fluid Particle, and Photon; Atomic-level Energy Kinetics: Length, Time, and Energy Scales; Scope of Heat Transfer Physics	1.1 - 1.8 Appendix F	**HW # 1**: 1.3, 1.4, 1.5, 1.7 (Due 1/12)
January 9	**Molecular Orbitals-Potentials-Dynamics, and Quantum Energy States**: Interatomic Forces, Potentials and Models; *Ab Initio* Interatomic Potential Calculations and Models; Statistical Ensembles, Energies, Temperature, and Partition Function; Hamiltonian Mechanics	2.1 - 2.4	**HW # 2** Interatomic Potential Using Gaussian Code
January 16	Monday: Martin Luther King Day Computational Classical Molecular Dynamics (MD) Simulation and Scales; Schrödinger Equation; Quantum Simple Harmonic Oscillator and for Free Electron Gas, Electronic Energy in Hydrogen-Like Atoms	2.5 - 2.6	**HW # 3** 2-D MD Gas Particle Code
January 23	**Carrier Energy Transport and Transition Theories**: Boltzmann Transport Equation (BTE); In- and Out-Scattering; Relaxation Time Approximation; Evaluation of Scattering and Energy Interaction Rates, Fermi Golden Rule	3.1 - 3.2 Appendix E	**HW # 4**
January 30	Maxwell Equations; Onsager Transport Coefficients; Stochastic Transport Processes (Langevin Equation); Green-Kubo (G-K) Autocorrelation Decay and Thermal Conductivity, Elastic Solid and Newtonian Fluid Conservation and Wave Equations and Scales	3.3 - 3.9 Appendix B	**HW # 5**
February 6	**Phonon**: Dispersion in Harmonic Lattice Vibration (Acoustic and Optical Phonons); Phonon Density of States; Reciprocal Lattice Space and Brillouin Zones; Lattice Specific Heat Capacity	4.1 - 4.3, 4.6 – 4.7	**HW # 6**: 3-D Ar FCC Phonon Dispersion Code
February 13	Phonon BTE and Callaway Lattice Conductivity Model (Single-Mode Relaxation Time); Phonon Scattering Relaxation Times; Cahill-Pohl Minimum Lattice Conductivity; Material Metrics of Lattice Conductivity (Slack Relation); Lattice Conductivity Decomposition, Phonon Boundary Resistance; Ultrasound Heating; Size Effects	4.9 - 4.12, 4.17 - 4.19 Appendix C Appendix D	**HW # 7** Case Study I: Phonon Conductivity of Cage-Bridge, Layered, and Filled-Cage Crystals
February 20	**Electron**: Schrödinger Equation for Electron Band Structure in Crystals; Electron Band Structure in One-Dimensional Ionic Lattice; Tight-Binding Approximation; *Ab Initio* Calculation of Band Structure; Full and Model Band Structures and Effective Electron Mass in Semiconductors; Periodic Electron Gas Model for Metals; Electron Density of States for Semiconductors and Fermi Level; Electron Specific Heat Capacity	5.2 - 5.8	**HW # 8** Tight-Binding Method Fermi Surface Graphing Code Materials Studio Code for Electronic Band Structure
February 27	Spring Recess		
March 6	Electron BTE for Semiconductors; Energy-Dependent and Average Relaxation Time; Semiconductor and Metal TE Transport Coefficients (Electrical Conductivity, Seebeck Coefficient, Peltier Coefficient, Electric Thermal Conductivity, and Wiedemann-Franz law); Electron Scattering by Phonons; Electron-Phonon Thermal Nonequilibrium and Cooling Length; Size Effects	5.9 - 5.13, 5.15, 5.17 - 5.19, 5.22	**HW # 9** Case Study II: Single- and Multistage Micro TE Cooler
March 13	**Fluid Particle**: *Ab Initio* Calculations of Quantum States, Quantum Fluid Particle Electronic, Translational, Vibrational, and Rotational Energy States and Partition Functions; Fluid Particle Specific Heat Capacity (Ideal Gas and Dense Fluid); Fluid Particle BTE; Equilibrium Energy Distribution Function; Binary Collision Rate; Relaxation Time and Mean Free Path; Theoretical Maximum Evaporation/Condensation Heat Transfer Rate	6.1 - 6.7	**HW # 10** Gaussian Code for CO_2 Rotational and Vibrational Quantum States

March 20	Ideal Gas Thermal Conductivity from BTE; Liquid Thermal Conductivity; Brownian Motion of Dispersed Solid Particles and Effective Liquid Conductivity; Fluid Particle-Surface Interactions and Flow Regimes; Thermophoresis; Adsorption and Desorption; Turbulent-Flow Structure and Boundary-Layer Transport; Thermal Plasmas; Size Effects	6.8 - 6.14	**HW # 11** Case Study III: Effective Thermal Conductivity of Nanogap; Extreme boiling heat transfer
March 27	**Photon**: Planck Distribution for Photon Gas (Blackbody Radiation); Lasers and Narrow Band Emission; Population Rate Equation for Photon Absorption and Stimulated and Spontaneous Emissions in Two-Level Electronic Systems; Einstein Coefficients, Absorption Coefficient and Cross-Section Area	7.1 - 7.2, 7.4	**HW # 12**
April 3	Photon Particle Treatment and BTE with Absorption, Emission, and Scattering Cross-Section Areas; Radiation Intensity and Equation of Radiative Transfer (ERT) and its Relation with Macroscopic Energy Equation; Optically Thick Limit of ERT and Radiant Thermal Conductivity; Wave (Coherent) Treatment of Photon (Photon Localization); Continuous and Band Absorption from FGR; Continuous and Band Emission and Surface Emissivity	7.5 - 7.10	**HW # 13**
April 10	Radiative and Nonradiative (Involving Phonon Emission) Decays and Quantum Efficiency; Anti-Stokes Fluorescence (Phonon Absorption) and Photon-Electron-Phonon Couplings (Laser Cooling of Solids); Gas Lasers and Laser Cooling of Atomic and Molecular Gases; Photovoltaic Solar Cell; Size Effects Course Evaluation (Online)	7.11 - 7.15	Case Study IV: Phonon-assisted photon absorption (laser cooling and solar cell)
April 17	**Classes End Tuesday, April 18** No class Tuesday, April 18		
Instructor	**Massoud Kaviany**, Office: 3444 G.G. Brown, Phone: 936-0402, email: **kaviany@umich.edu**		
Office Hours	Tuesdays and Wednesdays, 12:30 - 1:30, 3444 GGB		
Grade Policy	Homework: 100%		
Class Participation	5% extra points are given for strong class participation		
Homework	Problems are assigned every Thursday and are due the following Thursday. The homework should be posted on Canvas under Gradescope at the end of Thursday class (at 2:50 PM).		
Textbook	*Heat Transfer Physics*, M. Kaviany, Second Edition, Cambridge University Press, 2014		
Wikipedia article	Heat Transfer Physics *Wikipedia* article is at URL (with useful links) http://en.wikipedia.org/wiki/Heat_transfer_physics		