CHEN E 4112 Y TRANSPORT PHENOMENA
IN FLUIDS AND MIXTURES
Spring 2021

PREREQUISITES: A working knowledge of vector calculus, linear algebra and ordinary differential equations is needed. An undergraduate course in transport, and some exposure to methods in partial differential equations, are also needed.

DESCRIPTION: The course develops and applies a framework for continuum-level modeling of transport phenomena in fluids and their mixtures. The first part of the course considers simple fluids. Continuum balances of mass, energy and momentum (linear and angular momentum) are combined with linearized constitutive equations for the conductive fluxes of momentum and energy (Newton's law of viscosity and Fourier's law), the latter being consistent with the constraints demanded by the second law. Applications of the framework to classes of problems important in chemical engineering technologies are reviewed (conduction dominated energy transport, forced and free convection transport). In the second part of the course, a treatment of mixtures is given. Importantly, constitutive laws for species conductive fluxes are developed (e.g. Fick's law for binary, isothermal systems). Applications to modeling important classes of mass transport problems are reviewed, with empahsis on isothermal systems (e.g diffusion-reaction problems, analogy between energy and mass transport processes, transport in electrolyte solutions, sedimentation).

INSTRUCTOR: INSTRUCTOR C.J. Durning, 811A Mudd, cjd2@columbia.edu, Office hour TBD.

CLASS MEETING: M/W 11:40 AM - 12:55 PM.

REQUIREMENTS: Homeworks, Take Home Midterm (*tentatively* the week of March 15), Take Home Final exam (finals week).

OPTIONAL EXTRA CREDIT: Submit class notes during finals week.

HOMEWORKS: Readings and problems assigned approximately biweekly; Homeworks checked for submission/completeness/integrity, but not graded in detail; Solutions will be posted.

GRADES: Based on exams, homeworks.

REFERENCES:

1. D.C. Venerus, H.C. Ottinger, A Modern Course in Transport Phenomena, Cambridge University Press, NY (2018) (VO)
2. W.M. Deen, *Analysis of Transport Phenomena, 2nd. (US) Ed.,* Oxford University Press, NY (2012) (De)
3. R.B. Bird, W.E. Stewart, E.N. Lightfoot, *Transport Phenomena, 2nd Edition*, J. Wiley, NY (2002) (BSL)

SUPPLEMENTAL READINGS: To appear on CANVAS website.

CHEN E 4112 Y - Spring 2021 COURSE OUTLINE

1. **OVERVIEW / PRIMER** (1 week)**:**
   a. Continuum description of matter
      - locally averaged microstate
      - frames of reference; kinematics; Eulerian and Lagrangian descriptions
2. **NON-EQUIL THERMODYNAMICS (NET) OF SIMPLE FLUIDS** (3 weeks)**:**
   a. Eulerian balances and the second law
      - balances of mass, momentum, energy
      - second law, entropy inequality, non-equilibrium temperature, T
      - assessment of closure

   b. Development of constitutive laws for the conductive fluxes
      - frame-indifferent, linearized constitutive representations
      - second law $\Rightarrow$ local equilibrium relations, Newton's law of viscosity; Fourier's law
      - T explicit form of the energy equation

   c. Limiting cases
      - isotropic, rigid media; incompressible fluids; Boussinesq approximation
3. **APPLICATIONS OF NET FOR SIMPLE FLUIDS** (4 weeks):
   a. Energy conduction in "rigid media"

   b. Laminar forced convection energy transport in incompressible fluids
      - Graetz/Leveque problems at high Peclet number
      - forced convection energy transport from submerged, heated bodies and localized sources

   c. Laminar free convection energy transport
      - free convection in slots, from submerged, heated bodies; thermal plumes
4. **FRAMEWORK FOR ANALYSIS OF MIXTURES** (2 weeks):
   a. Framework for isothermal binary mixtures
      - minimal set of Eulerian balances: species mass balances and mixture momentum balance
      - assessment of closure
      - ad-hoc assignment of mixture conductive momentum flux
      - NET development for species diffusive fluxes (Fick's law)
5. **APPLICATIONS FOR ISOTHERMAL MIXTURES** (4 weeks)
   a. analogy between energy and mass transport

   b. mass transport under body fields
      - sedimentation
      - transport in electrolyte solutions and electrokinetic phenomena

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Course Calender

WEEK	DATES	REMARKS
1	Jan. 11/13	Overview, Math Review, Kinematics
2	Jan. 18/20	Balance Laws: Mass, Momentum, Energy
3	Jan. 25/27	NET of Simple Fluids: Constitutive Laws
4	Feb. 1/3	NET of Simple Fluids: Limiting Cases
5	Feb. 8/10	Energy Conduction in Rigid Media
6	Feb. 15/17	Forced Convection ET
7	Feb. 22/24	Forced/Free Convection ET
8	March 8/10	Free Convection ET
9	March 15/17	**Midterm**/Balances for Mixtures
10	March 22/24	Constitutive Laws for Mixtures
11	Mar 29/31	Diffusion Dominated MT
12	April 5/7	Trace Limit, ET/MT Analogy, Forced Convection MT
13	April 12/14	MT Under Body Fields
14	April 16-23	Reading Days/ **Final**