TAM 534: Non-Newtonian Fluid Mechanics & Rheology (grad 4 cr)
TAM 498 (ugrad 3 cr)

University of Illinois Urbana-Champaign
Spring 2024

TAM 534 and TAM 498 meet concurrently. TAM 498 is for undergraduate students (3 credits) and TAM 534 is for graduate students (4 credits) which involves advanced expectations on assessments.

Instructor: **Prof. Randy H. Ewoldt**
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Office: 4418 MEL (Mechanical Engineering Laboratory)
Lab: b220f MEL

TA: **TBD**

Lectures: Monday and Wednesday 1:00–2:50 PM
2045 LuMEB (Sidney Lu Mechanical Engineering Building)

Office Hours: TBD

Course Website: via Canvas

COURSE OVERVIEW

Rheology is interdisciplinary, integrating fluid mechanics, solid mechanics, material science, chemistry, physics, and mathematics to understand complex materials that defy basic definitions of fluid and solid.

Applications include additive manufacturing, polymer processing, soft robotics, biomaterials, food science, geophysics, and many other scenarios where materials violate Newton's law of viscosity or Hooke's law of elasticity.

You will learn material property interpretation, optimal measurement techniques, constitutive equations for predicting non-Newtonian flow and elastomeric soft matter deformation, and microstructural origins of behavior.

This course will expand your engineering toolbox to include soft matter and non-Newtonian fluids, help to integrate your understanding of mechanics from fluids, to solids, to things-in-between, and develop your experimental measurement skills with laboratory exercises to measure shear-thinning, viscoelasticity, and more.

You will learn how to relate complex mechanical properties to applications of interest to you, and how continuum-level behavior is associated with molecular and microscale structure across a

broad range of materials including polymer solutions and melts, colloidal suspensions, granular particle suspensions, pastes, emulsions, foams, surfactants, hydrogels, and biopolymer networks.

The course is designed for an interdisciplinary audience including all engineering disciplines (mechanical, materials, chemical, biological, civil, environmental, etc.), as well as chemistry, pharmacy, medicine, food science, geology, physics, biology, etc.

TEXTS (REQUIRED)

Macosko, Ewoldt, McKinley, *Rheology [DRAFT]* (2024?)
(draft chapters provided)

Macosko, *Rheology: principles, measurements, and applications* (1994)
(on reserve at UIUC Grainger Engineering Library - link)

TEXTS (USEFUL REFERENCES)

(Many on reserve at UIUC Grainger Engineering Library)

Bird, Armstrong, Hassager, *Dynamics of polymeric liquids* vol.1, ed.2 (1987) (link)

Larson, *The structure and rheology of complex fluids* (1999) (link)

Rubinstein, Colby, *Polymer physics* (2003) (link)

Lodge, Hiemenz, *Polymer chemistry* (2021) (link) (2007 version available at library link)

Mewis, Wagner, *Colloidal suspension rheology* (2011) (link – online access via library)

STUDENTS COMPLETING THIS COURSE WILL BE ABLE TO:

1. Explain the four key rheological phenomena
2. Understand rheological material functions related to viscoelasticity, shear thinning and shear thickening, nonlinear viscoelasticity, extensional viscosity, and thixotropy
3. Relate rheological properties to applications such as additive manufacturing, injectable hydrogels, energy storage flow batteries, concrete, food science, adhesives, toys, geophysics, and their own career or research interests
4. Identify unifying concepts across mechanics of fluids and solids
5. Use simple molecular and microstructural theories to understand trends in continuum-level rheological properties
6. Experimentally measure rheological material functions
7. Identify good and bad rheological data
8. Take photos and videos that document specific aspects of rheological complexity
9. Perform signal processing and data analysis
10. Fit models to rheological data

PREREQUISITES

This interdisciplinary course is designed for a broad audience with diverse disciplinary backgrounds across science and engineering. Instructor permission is the ultimate criterion for prerequisite approval. Below are guidelines.

TAM 498 students should have completed *introductory* coursework in at least one of the five key areas below.

TAM 534 students should have completed or be concurrently enrolled in *intermediate* coursework in at least one of the five key areas below.

Five key areas: fluid mechanics, solid mechanics, materials processing, polymer science, or colloid science.

Introductory coursework may include, for example:

TAM 251: Introductory Solid Mechanics

MSE 206: Mechanics for MatSE

AE 321: Mechs of Aerospace Structures

ME 310: Fundamentals of Fluid Dynamics

TAM 335: Introductory Fluid Mechanics

AE 311: Incompressible Flow

PHYS 326: Classical Mechanics II

Intermediate coursework may include, for example:

TAM 435: Intermediate Fluid Mechanics

TAM 451: Intermediate Solid Mechanics

MSE 450: Polymer Science & Engineering

CHEM 482/MSE 458: Polymer Physics

CHEM 488/MSE 480: Surfaces and Colloids

CHBE 421: Momentum and Heat Transfer

FSHN 460 Food Processing Engineering

STUDENT ASSIGNMENTS & GRADING

We have a lot to cover in just one semester. This course will move fast and require you to read, solve problems, study, and complete projects outside of class.

Homework	20%
Notes	10%
Oral Exams	30% (This may be new for you! Many students appreciate this style.)
Paper critique	20% (Graduate students work individually, undergraduates in groups)
Final Project	20% (Graduate students work individually, undergraduates in groups)

Homework: Exactly what you think.

Notes: For each assigned chapter reading, you will submit one page of self-prepared notes that summarizes the most important concepts, terminology, and equations. You must choose carefully what to include and what not to include. Use whatever formatting and text size you like to make this a useful reference for yourself in the future. You will bring these notes to oral exams as a reference and be asked to defend your decisions of what is included and what is not included in the one-page summaries.

Oral Exams: We will meet multiple times for 20-30 minutes one-on-one to go over your self-prepared notes, lectures, homework, and assigned readings. Your grade will depend upon the level of understanding you demonstrate. After each one-on-one meeting, you will be provided a written report discussing your performance. This is unusual but has been used successfully in many courses at this high level. Do not hesitate to ask questions.

Paper Critique: Summary and analysis of a published research paper presented to the class. This is a chance to assess your ability to read the literature and expand your knowledge beyond the fundamental concepts of the course.

Final Project: Go forth and measure! The project will involve analyzing, interpreting, and self-critiquing rheological data and relating it to flow and deformation behavior and underlying microstructure. The project is intended to give students an opportunity to apply knowledge, synthesize multiple elements of the course, and extend course content in new directions (the highest level of Bloom's Taxonomy of Learning Domains).

AGENDA (TENTATIVE)

1. Introduction and Big Ideas
   Stress and strain and strain-rate
   Material Functions
2. Linear Viscoelasticity
   +Lab: relaxation time
3. Nonlinear Viscous Fluid
   +Lab: shear thinning
4. Nonlinear Elastic Solid
5. Nonlinear Viscoelasticity
   +Lab: shear normal stress difference
6. Thixotropy and Yield-Stress Fluids
7. Rheometry: shear (wall-driven)
8. Rheometry: shear (pressure-driven)
9. Rheometry: how to avoid bad data
10. Rheometry: extension
11. Molecular and microstructural origins of rheological phenomena (integrated throughout)

ADDITIONAL INFORMATION FOR THE UNIVERSITY OF ILLINOIS AND THE GRAINGER COLLEGE OF ENGINEERING

Academic Integrity

The University of Illinois Urbana-Champaign Student Code should also be considered as a part of this syllabus. Students should pay particular attention to Article 1, Part 4: Academic Integrity. Read the Code at the following URL: http://studentcode.illinois.edu/.

Academic dishonesty may result in a failing grade. Every student is expected to review and abide by the Academic Integrity Policy: https://studentcode.illinois.edu/article1/part4/1-401/. Ignorance is not an excuse for any academic dishonesty. It is your responsibility to read this policy to avoid any misunderstanding. Do not hesitate to ask the instructor if you are ever in doubt about what constitutes plagiarism, cheating, or any other breach of academic integrity.

Health and Safety

Following University policy, all students are required to engage in appropriate behavior to protect the health and safety of the community. If you feel ill or have symptoms of COVID, you should not go to class.

Please refer to the University of Illinois Urbana-Champaign's COVID-19 website at https://covid19.illinois.edu for further information. Thank you for respecting all of our well-being so we can learn and interact together productively.

Emergency Action Plans

When we're faced with any kind of emergency – like fire, severe weather, or if someone is trying to hurt us – we have three options: run, hide, or fight. Take a moment to learn the different ways to leave this building and figure out the best place to go in case of severe weather. If you want to better prepare yourself for any of these situations, visit https://police.illinois.edu/em/run-hide-fight/. Remember you can sign up for emergency text messages at http://emergency.illinois.edu/

Disability-Related Accommodations

To obtain disability-related academic adjustments and/or auxiliary aids, students with disabilities must contact the course instructor and the Disability Resources and Educational Services (DRES) as soon as possible. To contact DRES, you may visit 1207 S. Oak St., Champaign, call 333-4603, e-mail disability@illinois.edu or go to https://www.disability.illinois.edu. If you are concerned you have a disability-related condition that is impacting your academic progress, there are academic screening appointments available that can help diagnosis a previously undiagnosed disability.

Religious Observances

Illinois law requires the University to reasonably accommodate its students' religious beliefs, observances, and practices in regard to admissions, class attendance, and the scheduling of examinations and work requirements. You should examine this syllabus at the beginning of the semester for potential conflicts between course deadlines and any of your religious observances. If a conflict exists, you should notify your instructor of the conflict and follow the procedure

at https://odos.illinois.edu/community-of-care/resources/students/religious-observances/ to request appropriate accommodations. This should be done in the first two weeks of classes.

Family Educational Rights and Privacy Act (FERPA)
Any student who has suppressed their directory information pursuant to Family Educational Rights and Privacy Act (FERPA) should self-identify to the instructor to ensure protection of the privacy of their attendance in this course. See https://registrar.illinois.edu/academic-records/ferpa/ for more information on FERPA.

Sexual Misconduct Reporting Obligation
The University of Illinois is committed to combating sexual misconduct. Faculty and staff members are required to report any instances of sexual misconduct to the University's Title IX Office. In turn, an individual with the Title IX Office will provide information about rights and options, including accommodations, support services, the campus disciplinary process, and law enforcement options.

A list of the designated University employees who, as counselors, confidential advisors, and medical professionals, do not have this reporting responsibility and can maintain confidentiality, can be found here: wecare.illinois.edu/resources/students/#confidential.

Other information about resources and reporting is available here: wecare.illinois.edu.

Anti-Racism and Inclusivity Statement
The Grainger College of Engineering is committed to the creation of an anti-racist, inclusive community that welcomes diversity along a number of dimensions, including, but not limited to, race, ethnicity and national origins, gender and gender identity, sexuality, disability status, class, age, or religious beliefs. The College recognizes that we are learning together in the midst of the Black Lives Matter movement, that Black, Hispanic, and Indigenous voices and contributions have largely either been excluded from, or not recognized in, science and engineering, and that both overt racism and micro-aggressions threaten the well-being of our students and our university community.

The effectiveness of this course is dependent upon each of us to create a safe and encouraging learning environment that allows for the open exchange of ideas while also ensuring equitable opportunities and respect for all of us. Everyone is expected to help establish and maintain an environment where students, staff, and faculty can contribute without fear of personal ridicule, or intolerant or offensive language. If you witness or experience racism, discrimination, micro-aggressions, or other offensive behavior, you are encouraged to bring this to the attention of the instructor if you feel comfortable. You can also report these behaviors to the Bias Assessment and Response Team (BART) (https://bart.illinois.edu/). Based on your report, BART members will follow up and reach out to students to make sure they have the support they need to be healthy and safe. If the reported behavior also violates university policy, staff in the Office for Student Conflict Resolution may respond as well and will take appropriate action.