Macromolecular Solids
MSE 455
Spring Semester 2022

Instructor:

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Teaching Assistant:

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Course Website:

Canvas: http://canvas.illinois.edu

Text:

Mechanical Properties of Solid Polymers, 3rd ed. (2013)
by I. M. Ward and J. Sweeney
This textbook is available for free (as a PDF) on the Illinois library website (library.illinois.edu). The text can also be purchased on Amazon.

Lectures:

We will have approximately 28 lectures during the semester. Lectures will be given on Tuesdays and Thursdays between 11am-12:20pm (Central time) in **Room 2018 Campus Instructional Facility (CIF)**. The complete schedule is listed in the syllabus. Lectures will be given in person to the extent possible in Spring 2022. If circumstances should arise due to COVID, following guidance from the university, lectures will be delivered in an online virtual (synchronous) format.

Problem Sets & Exams:

There will be approximately 5-6 problems sets. There will be 2 exams and no final exam. The second exam will be given during the final exam timeslot for the course and may include some amount of cumulative material from the entire course.

Grading:

Homework	25%
Exam #1	25%
Exam #2	30%
Final project	20%

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Course Description:
This course is designed to provide students with the tools to solve quantitative problems in macromolecular science with a particular focus on the solid phase. Broadly, the course focuses on the mechanical behavior of amorphous and semi-crystalline polymers. The course begins with an overview of polymer structure, conformation, and isomerism, followed by a detailed discussion of the glass transition and properties of crystalline polymers. Additional topics include polymer characterization, polymer morphology, and orientation effects; rubber elasticity, polymer linear viscoelasticity using Boltzmann superposition and mechanical models; measurement of viscoelastic properties; polymer relaxation and transitions; polymeric yield phenomena and plastic flow; deformation mechanisms; fracture and craze formation; impact and fatigue.

Course Textbook:

- *Mechanical Properties of Solid Polymers*, I. M. Ward and J. Sweeney, Wiley, 3rd edition (2013). Acronym: **WS**

(Unofficial) Course Textbook:

- *Polymer Chemistry*, T. Lodge and P. C. Hiemenz, 3rd ed., CRC Press (2020). Acronym: **L**

Other textbooks that may be useful:

Polymer physics:

- *An Introduction to Polymer Physics*, D. I. Bower, Cambridge (2002). Acronym: **B** – (this textbook is available for free on the Illinois university library website)
- *Polymer Physics*, M. Rubinstein and R. H. Colby, Oxford (2003). Acronym: **RC**

Mathematics and mathematical principles:

- *Advanced Engineering Mathematics*, M. Greenberg, 2nd ed., Prentice Hall (1998). Acronym: **G**
- *Elementary Differential Equations*, Boyce and DiPrima, 9th ed., Wylie (2008). Acronym: **BD** – (e.g. discussion on Laplace transforms)
- *Incompressible Flow*, R. L. Panton, 3rd edition, Wiley (2005). Acronym: **P** – (e.g. discussion on index or Einstein notation)

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Course Outline (tentative)

Lec	Date	Topic	Reading*
Lec 1	Jan 18	Course introduction; general concepts in polymer structure	WS §1; L §1
Lec 2	Jan 20	Classification of polymers; polymer architecture	L §1
Lec 3	Jan 25	Molecular weight characterization	L §1
Lec 4	Jan 27	Isomerism; polymer conformations	L §6
Lec 5	Feb 1	Polymer conformations: FJC, FRC, HRC	L §6
Lec 6	Feb 3	Conformations: WLC, persistence length, R_g, distributions	L §6
Lec 7	Feb 8	Amorphous polymers & glass transition; thermodynamics	L §12.1-12.4; 12.6
Lec 8	Feb 10	Glass transition: free-volume concepts, VFT, properties	L §12.1-12.4; 12.6
Lec 9	Feb 15	Polymer crystallinity: structure, measurement, unit cells	B §3.4; B §4
Lec 10	Feb 17	Intro to scattering: light, SAXS, WAXS	L §8.1-8.2, 13.1-13.2
Lec 11	Feb 22	Polymer crystallinity: thermodynamics of melting	L §13.3-13.4
Lec 12	Feb 24	Polymer crystallinity: kinetics, nucleation, growth	L §13.5-13.6
Lec 13	Mar 1	Molecular relaxation in crystalline polymers; NMR analysis	B §5 & WS §10
Lec 14	Mar 3	Deformation, stress, strain, constitutive equations	WS §2; B §6.1-6.2
Lec 15	Mar 8	Linear viscoelasticity & mechanical models	WS §5.1-5.2; L §11.2
Lec 16	Mar 10	Linear viscoelasticity: SLS, dynamic behavior	WS §5.2, 5.3, 5.4
	Mar 15	Spring Break - no class	
	Mar 17	Spring Break - no class	
Lec 17	Mar 22	Review	
	Mar 24	Exam #1	
Lec 18	Mar 29	Time-temperature superposition & WLF equation	L §12.5; WS §7.1-7.4
Lec 19	Mar 31	Modeling linear viscoelasticity, Boltzmann superposition	L §11.3; WS §7.1-7.4
Lec 20	Apr 5	Rubber elasticity: networks, Carothers equation, Flory	L §10; WS §4
Lec 21	Apr 7	Rubber elasticity: elastomers, thermodynamics	L §10; WS §4
Lec 22	Apr 12	Rubber elasticity: deformation of Gaussian networks	L §10; WS §4
Lec 23	Apr 14	Mechanical properties of solid polymers: intro	L §12.7
Lec 24	Apr 19	Yielding, instability, and Consideré construction	WS §12.1-12.3
Lec 25	Apr 21	Molecular interpretation of yield & rate dependence	WS §12.4-12.6
Lec 26	Apr 26	Breaking, brittle fracture	WS §13.1-13.3
Lec 27	Apr 28	Crazing	WS §13.4-13.5
Lec 28	May 3	Course Project Due & Review	
	May 12	Exam #2 - final exam time slot (8am, Thursday, May 12)	

*Refer to page 2 of the syllabus for textbook acronyms.

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Problem Sets (tentative)

Assignment	Handout Date	Due Date
HW 1	Jan 25	Feb 8
HW 2	Feb 8	Feb 22
HW 3	Feb 22	Mar 8
HW 4	Mar 29	Apr 12
HW 5	Apr 12	Apr 26

Important Dates
Exam #1: Thursday, March 24
Exam #2: Thursday, May 12, 8:00am - 11:00am (university final exam schedule)
Project Due: Tuesday, May 3

Course Project - choose one of two options
Option 1 - Critical review of literature
For this option, you are asked to search the primary research literature (journal publications) and to write a critical review of a publication reporting on polymer design, development, or characterization from the recent literature. Your paper should constitute a *critical review* of a current topic in polymer science, focusing on macromolecular solids. You should focus on recent developments (over the last 5 years), but consideration should also be given to classic papers from the literature where appropriate. The paper should be sufficiently focused so that you can delve into the topic with reasonable depth. The paper should contain the following sections: abstract (200 word maximum), introduction/motivation, brief summary of work, critique of scientific contribution (including possible errors in original scientific contribution), ideas for potential new directions for 'next' experiments, conclusion, and references. More information for the paper will be provided later in the semester. General length: 4-5 pages, not including figures.

Option 2 - Quantitative analysis of polymer data
For this option, you will be asked to quantitatively analyze a set of mechanical characterization data from a polymer sample. This could include dynamic mechanical analysis (DMA) or rheological data such as linear viscoelasticity and dynamic moduli. You will be expected to write a brief paper summarizing your results, including plots and figures showing your analyzed data, with physical interpretations of the results. The summary paper should contain the following sections: abstract (200 word maximum), introduction and discussion of polymeric system, overview of experimental method(s) and quantitative analysis methods, results & discussion, ideas for potential new directions for 'next' experiments, and conclusion. More information for the project will be provided later in the semester. General length: 4-5 pages, not including figures or supplementary sections.

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Course Policies:

- **Submitting assignments.** All assignments are due on the assignment due date (no later than 11:59pm) as listed in the syllabus. Please submit your coursework in class or on the Canvas website by following the instructions provided in class or by the TA.

- **Late Assignments.** All late assignments will be subject to a 25% per day penalty, unless the absence is officially excused. Missed exams without a valid excuse will result in a zero on the exam.

- **Academic integrity** For all individual assignments, the work that you turn in must be your own work. Working in groups to discuss overall approaches to solving problems is fine (and encouraged), but you need to turn in your own work for individual assignments. Strict penalties are associated with any forms of cheating. University and departmental policies will be followed in the case of any suspected cheating incidents. You are encouraged to read and carefully consider the University of Illinois at Urbana-Champaign Student Code as a part of this syllabus. Students should pay particular attention to Article 1, Part 4: Academic Integrity. Please read the Code at this 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(s) if you are ever in doubt about what constitutes plagiarism, cheating, or any other breach of academic integrity.

- **Copyright Course Materials.** All materials for this course are considered copyright of the University of Illinois at Urbana-Champaign. It is wholly unacceptable for students to post course materials (homeworks, quizzes, exams, solutions, lecture notes, etc.) in public places, including unauthorized websites, for sale or otherwise. Any act of making course materials available on the WWW, or in any other format, is considered copyright violation.

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Sexual Misconduct Reporting Obligations: 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.

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.

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.

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.

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Statement on Anti-Racism:
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 course director 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.