Chemical Engineering 160/260
Polymer Science and Engineering

Lecture 1 - Introduction

January 10, 2001

Reading: Sperling, Ch 1 and Ch 2

Administrative Details

- Instructor: Curt Frank
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- TA: Gabe Cronin
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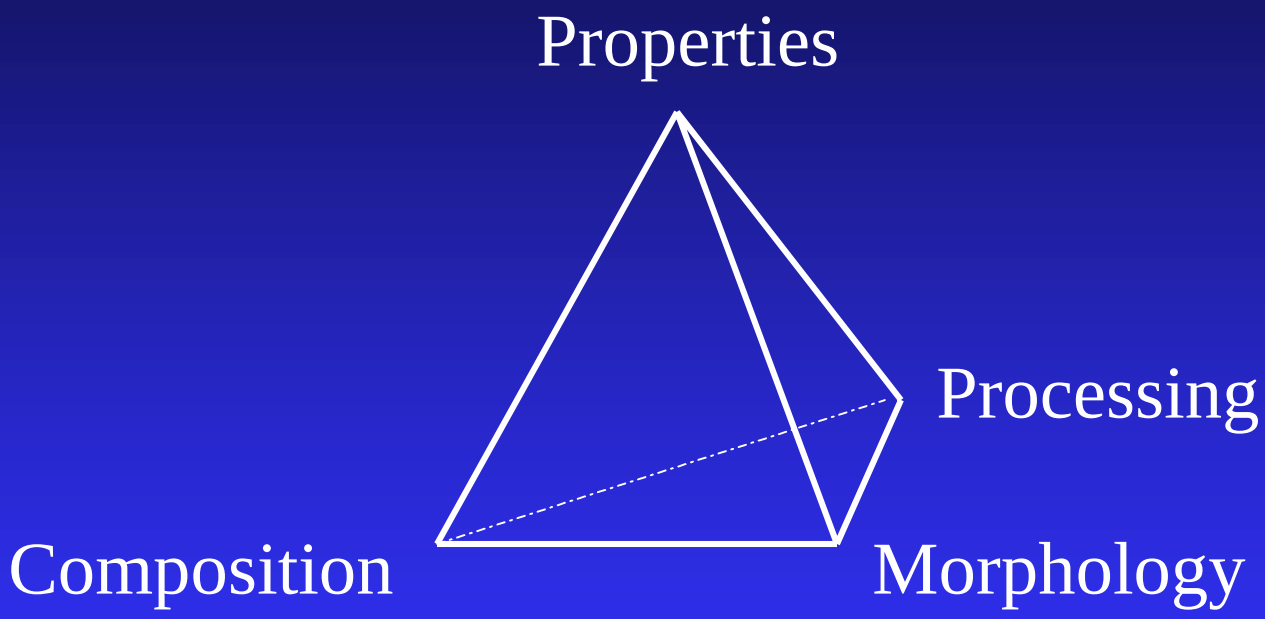
- Lecture 10:00 - 10:50 am, MWF
- Text: Introduction to Physical Polymer Science, L.H. Sperling, 2nd Ed.
- 7-8 problem sets
- 1 midterm, final
- For graduate credit: 15-page critical review

Structure-processing-property Relationships



Polymers are <u>materials</u> whose properties depend strongly on their processing history.

Composition:
Molecular weight
Molecular weight distribution
Stereoregularity
Copolymer comp.

Processing:
Thermal history
Stress/strain history
Environmental exposure

Morphology:
Degree of crystallinity
Crystal structure
Crystal orientation
Mesomorphic order

Properties:
Modulus
Tensile strength
Impact strength
Dielectric constant

Course Objectives

- To illustrate how molecular structure and molecular weight govern organization within bulk materials.
- To characterize the thermo-physical properties (glass transition, melting/crystallization, mesomorphism) in terms of molecular structure.
- To demonstrate the statistical nature of macromolecular science.
- To illustrate how polymer chain entanglements influence the time-dependent properties in solution, melt, and bulk.

Course Outline

- Ch 1: Introduction to Polymer Science
- Ch 2: Chain Structure and Configuration
- Ch 3: Molecular Weights and Sizes
- Ch 4: Concentrated Solutions and Phase Separation Behavior
- Ch 5: The Amorphous State
- Ch 6: The Crystalline State
- Ch 7: Polymers in the Liquid Crystalline State
- Ch 8: Glass-Rubber Transition Behavior
- Ch 9: Cross-linked Polymers and Rubber Elasticity
- Ch 10: Polymer Viscoelasticity and Rheology
- Ch 11: Mechanical Behavior of Polymers

Lecture Outline

- Historical significance
- Definitions
- Importance of molecular weight
- Classification schemes
- Commercial production figures
- Applications

Themes of the Chemical Industry: 1923-1998

- Establishment of the US chemical industry
- Growth of petrochemicals
- World Wars I and II
- Expansion of polymers
- Environmental challenges and responses
- Corporate acquisition, merger, and reinvention
- Birth and adolescence of biotechnology

Distinguished Contributors to Polymer Science

- Hermann Staudinger,1953 Nobel Prize
- Wallace Carothers
- Herman F. Mark
- Carl (Speed) Marvel
- Karl Ziegler, Giulio Natta, 1963 Nobel Prize
- Paul J. Flory, 1974 Nobel Prize
- Pierre Gilles de Gennes, 1991 Nobel Prize
- Alan Heeger, Allan McDermott, 2000 Nobel Prize

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Definitions

- ***Monomer*** - molecule with minimum functionality of two that reacts to form the structural units of the polymer
- ***Oligomer*** - short chain synthesized from reaction of several monomers (dimer, trimer, tetramer . . .)
- ***Polymer*** - macromolecule generated through sequential reaction of a small number of elementary units
- ***Repeating unit*** - structure composed of the minimum number of structural units necessary to generate the polymer
- ***Degree of polymerization*** - number of repeating units

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As the molecular weight increases, so does:

- Tensile strength
- Impact strength
- Toughness
- Creep resistance
- Stress-crack resistance
- Elongation to break
- Reversible elasticity
- Melting temperature
- Melt viscosity
- Difficulty of processing

Outline

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Classification by Origin

- Synthetic organic polymers
- Biopolymers (proteins, polypeptides, polynucleotides, polysaccharides, natural rubber)
- Semi-synthetic polymers (chemically modified biopolymers)
- Inorganic polymers (siloxanes, silanes, phosphazenes)

Classification by Chain Structure

- Linear chains
- Branched chains
- Stars
- Polymer networks
- Semi-interpenetrating networks
- Interpenetrating networks

Classification by Monomer Composition

- Homopolymer

  AAAAAAAAAAAAAAAA
- Random copolymer

  ABAABABBBAABAABB
- Alternating copolymer

  ABABABABABABABAB

Classification by Monomer Composition

- Block copolymer

  AAAAAAAAABBBBBBBBB

- Graft copolymer

  AAAAAAAAAAAAAAAAAA

  B B B

  B B B

Classification by Chain Configuration

- Monomer orientation
  - Head-to-tail
  - Head-to-head
- Geometric or cis-trans isomerism
- Stereoisomerism or tacticity
  - Isotactic
  - Syndiotactic
  - Atactic

Classification by Thermal Behavior

- ***Thermoplastics*** - materials become fluid and processible upon heating, allowing them to be transformed into desired shapes that are stabilized by cooling
- ***Thermosets*** - initial mixture of reactive, low-molar mass compounds reacts upon heating in the mold to form an insoluble, infusible network

Classification by Application

- Plastics
- Fibers
- Elastomers
- Coatings
- Adhesives

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Production of Thermoplastics 1998 (10^6 lb)

- Polyethylene
  - Low density (<0.940 g/cm^3) 7,578
  - Linear low density (<0.940 g/cm^3) 7,227
  - High density (>0.940 g/cm^3) 12,924
- Polyvinyl chloride and copolymers 14,502
- Polypropylene 13,825
- Styrene polymers
  - Polystyrene 6,327
  - Acrylonitrile-butadiene-styrene 3,086

Production of Thermosets 1998 (10^6 lb)

Phenolic	3,940
Urea	2,581
Unsaturated polyester	1,713
Epoxy	639
Melamine	290

Production of Synthetic Fibers 1998 (10^6 lb.)

- Noncellulosic fibers
  - Polyester 3,911
  - Nylon 2,847
  - Olefin 2,800
  - Acrylic 346
- Cellulosic fibers
  - Acetate and rayon 365

Production of Synthetic Rubber 1998 (10^6 lb.)

Styrene-butadiene rubber	960
Polybutadiene	580
Ethylene-propylene	321
Nitrile	89
Polychloroprene	72

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Packaging Applications

- Food wrapping
- Bottles
- Blister packs
- Trash bags and grocery sacks
- Shrink wrap
- Foam packing

Medical Applications

- Catheters
- Hip joint replacements
- Artificial limbs (legs, feet, arms)
- Artificial organs (heart, blood vessels, valves)
- Dental fillings, bridges, and coatings
- Disposable surgical clothes and instruments
- Eyeglass frames and lenses

Recreational Applications

- Boat hulls, masts, kayaks, surfboards, and sails
- Rackets, golf clubs, vaulting poles, and oars
- Bobsleds, dune buggies, and automobiles
- Athletic shoes
- Skis, ski poles, ski boots, and ski lift chairs
- Golf ball covers and golf club shafts
- Bicycle parts, helmets, and pads

Entertainment Applications

- Stereo and television components
- VCR tapes and housings
- Cases for radios, tape players, tapes, and CDs
- Toys

Textile Applications

- Clothing
- Carpets
- Non-woven fabrics
- Diapers and other disposables
- Upholstered fabrics for furniture
- Draperies and wall paper material

Construction and Home Applications

- Moldings
- Sprinklers and pipes
- Counter tops
- Sinks, shower stalls, and plumbing fixtures
- Flooring (vinyl and carpeting)
- Paint

Transportation Applications

- Automotive bodies, body panels, trim, and seats
- Aerospace components
- Train, monorail, and light rail cars
- Seat covers and dashboard covers
- Truck bed liners
- Gas tanks

Industrial Applications

- Pipes, valves, and tanks
- Gears and housings
- Adhesives and coatings
- Vibration damping pads
- Electrical circuit boards
- Wire insulation and connector devices
- Gaskets and sealants

Information Technology Applications

- Photoresists for microprocessor fabrication
- Interlayer dielectrics for microprocessor fabrication
- Alignment layers for liquid crystal displays
- Lubricants for computer hard disks