Physical Chemistry of Polymeric Materials

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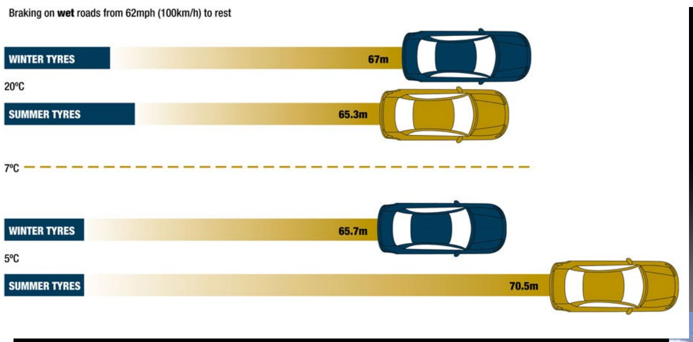
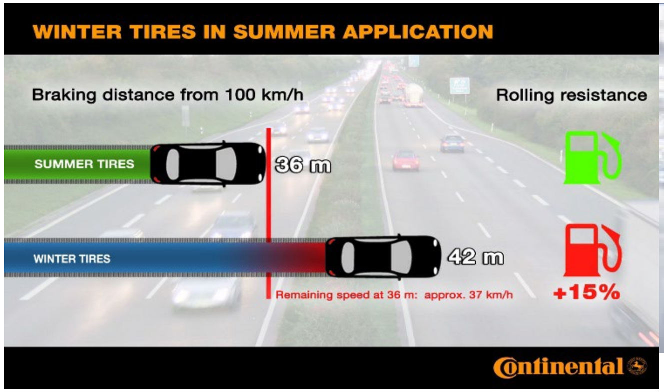
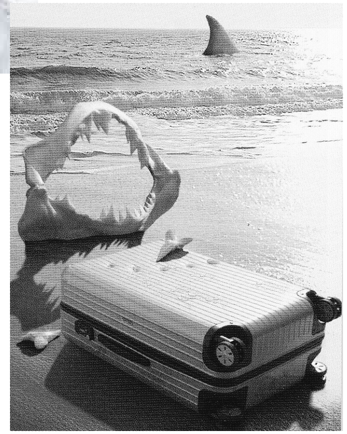
EPFL

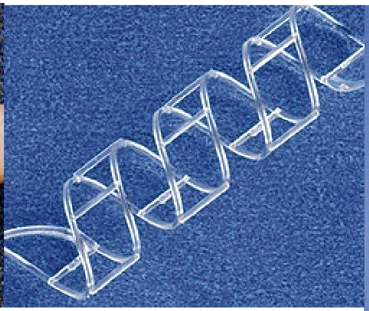
Polymers are Everywhere !



Silly Putty







www.rimowa.de

Goals of the Course

- Provide a basic understanding of the physical and physicochemical principles, which result from the chainlike structure of synthetic macromolecules.

- Able to predict major characteristics of a polymer from its chemical structure and molecular architecture, and to select the appropriate plastic material for a given application.

Course Organization - Online

Tuesday and Wednesday
10:15 – 12:00 DIA 004

eva.klok@epfl.ch

1. Cours: ex cathetra
   study by yourself of subjects given per week as a preparation for the explanation and discussion in class.

2. Recitations Some exercises will be discussed during class and will be integrated in the lecture
   series with all exercises available during the semester from http://moodle.epfl.ch,
   solution manual will be available on moodle

3. Assessment: During the semester:
   1. **Paper presentation in person** (during the exercise sessions). 10pt
   2. **Literature study** (after the end of the semester; submission date 08.06.2025, 23h59) 30pt

Study Material

1. T.P. Lodge, P.C. Hiemenz, Polymer Chemistry, 3rd edition, CRC Press 2020.

   e-book: link on moodle

   http://search.ebscohost.com/login.aspx?direct=true&scope=site&db=nlebk&db=nlabk&AN=2512676

   hardcopies are available at the liberary

2. M Rubinstein, R.H. Colby, Polymer Physics, Oxford University Press 2003

3. L.H. Sperling, Introduction of Physical Polymer Science 4th edition, Wiley Interscience 2005.

4. D. Myers, Surfaces, interfaces, and colloids: principles and applications, 2nd edition, Wiley-VCH, 1999.

5. Lecture notes (available from http://moodle.epfl.ch)

Course Outline

week	Topic	Reading
1	Introduction / Dilute Solution	Hiemenz chap. 7
2	Dilute Solution/ Polymer Structure in Solution	Hiemenz chap. 6
3	Molecular Weight Determination	Hiemenz chap. 8 + 9
4	Concentrated Solution and Phase Behavior	Hiemenz chap. 7
5	Amorphous Phase Crystalline Phase	Hiemenz chap. 12 Hiemenz chap. 13
6	Crystalline Phase Characterization of Polymers - Methods	
7	Glass Transition	Hiemenz chap. 12
8	Rubber Elasticity	Hiemenz chap. 10
9	Viscoelasticity	Hiemenz chap. 11
	Easter Break	
10	Viscoelasticity	
11	Surfaces and Interfaces	Myers chapt. 17
12	Characterization of Surfaces	
13	No course – Time for literature study	
14	No course – Time for literature study	

Assessment Part I - Paper Presentation

The objective of this part of the assessment is to help you to appreciate the relevance of this course in the context of the broader field of polymer materials science.

Organization:

1. Select an article, with a focus on polymer characterization, processing or properties (i.e. not synthesis !), that you find interesting from the journals
   Macromolecules (https://pubs.acs.org/journal/mamobx) and
   ACS Applied Polymer Materials (https://pubs.acs.org/journal/aapmcd),
   which has been published January 1, **2025** or more recent.
2. Everyone will present in person their paper in form of a 10 min presentation (4 – 5 ppt slides max) during the exercise session of the class (a detailed schedule will be made available in due course).
3. The PowerPoint presentation should be structured as follows, and cover the following elements:
   1) Slide 1: copy and paste the first page of the paper.
   2) Slide 2: explain why you have selected this paper.
   3) Slide 3: What is the technological / scientific problem or hypothesis that the authors of this study have tried to address ?
   4) Slide 4: What are the polymer(s) that have been investigated in this paper?
   5) Slide 5: What are the scientific methods / characterization techniques that this paper uses (just mentioning the names, without detailed explanation)?

Assessment Part II - Literature Study

1. Choose one publication (available from 10.03.2025 on moodle).
2. Study the paper and complete the questionnaire available as template (word file) on moodle.
3. Upload your completed questionnaire as pdf on moodle until 08.06.2025, 23h59. (e-mail submission is not accepted!)

Guidelines :

- *Read the article that you have selected and discuss the 9 points given in form of questions that are listed below.*
- *Your report should be at least 5 pages (maximum 20).*
- *Do not copy and paste text from the article, but provide answers in your own words. You may copy figures from the article to support your answers. If needed, you are also welcome to consult additional articles or books. If you do so, please make sure to cite these correctly.*
- *Make sure to use proper references if you use information or data from other sources. References normally should be to primary resources (articles from journals or books) and not websites.*

Template for Literature Study

PHYSICAL CHEMISTRY of POLYMERIC MATERIALS

Report on Literature Study

Name:____________________________________ sciper:_______________

ARTICLE:
Titel: **Phase diagrams of quasi-binary polymer systems with *LCST/UCST* spinodals and hour-glass cloud-point curves**

Author(s): **Stephen J. Mumby*, Caibao Qian and B. E. Eichinger**

Journal: **Polymer** Year: **1992** Vol.: **33 (23)** Pages: **5105 - 5108**

POINTS TO DISCUSS:

1) What is the analytical problem, which the authors are trying to address in this study?

2) Which experimental technique(s) do the authors use in this study? Briefly summarize the basic principles of these polymer analytical methods.

3) Which polymer(s) do the authors study? Provide the chemical structure (no description of the synthesis) and molecular weight(s). Why these polymers are chosen?

4) Give a summary of the main results of the study.

5) Briefly describe in your own words the conclusions of the authors?

6) Are there any other analytical tools (in addition to those used in this article), which the authors could have used?

7) What did you find particularly interesting about this article?

8) If you would have the chance to meet the authors and discuss their paper, which scientific question(s) would you ask?

9) Find 1 scientific paper that investigates a similar problem with the same analytical methods but on another polymer or other polymers. Briefly summarize this article (max. ½ page).

REFERENCES: given in ACS citation style (see also next slides)
A. Author, B. Author, *Journal Name*, **Year**, *Volume*, page X-page Y
If you need to cite a webpage give the complete URL

POLYMER, 1992, Volume 33, Number 23, 5105 - 5108

Phase diagrams of quasi-binary polymer systems with *LCST/UCST* spinodals and hour-glass cloud-point curves

Stephen J. Mumby*, Caibao Qian and B. E. Eichinger

BIOSYM Technologies, Inc., 9685 Scranton Road, San Diego, CA 92121, USA
(Received 24 January 1992)

A generalized Flory-Huggins theory is utilized to investigate liquid-liquid phase diagrams of quasi-binary polymer solutions and blends, in which one component may be polydisperse. A temperature and concentration dependent Z parameter is employed. It is illustrated that a polymer solution, in which the polymeric component has a Schulz-Zimm molecular weight distribution, may exhibit combined lower critical solution temperature/upper critical solution temperature spinodals and hour-glass cloud-point curves (CPCs). This is a direct consequence of the critical points being offset from the extrema of the CPCs and spinodals for quasi-binary systems, in contrast to true binary systems (such as solutions and blends of monodisperse polymers). Thus, for quasi-binary systems, it may be hazardous to infer the behaviour of spinodals from observations of CPCs or vice versa.

Please take over this outline for your report

Citation - Book

Essential Bibliographic: Guide to bibliographic references writing (V1.00)
CC BY-SA March 2021 - EPFL Library (https://infoscience.epfl.ch/record/291407)
Taken citation style: ACS

Book

Title
Author
Publication place
Publication date
Publisher
Edition (if it is not the first one)

(1) Bartling, S.; Frieske, S. *Opening science: the evolving guide on how the Internet is changing research, collaboration and scholarly publishing*; SpringerOpen: Cham, 2014.

Citation - Journal

Journal Article
Article title
Author(s)
Journal title
Volume
Issue
Pages
Publication date
(DOI or URL + access date)

POLYMER, 1992, Volume 33, Number 23, 5105 - 5108

Phase diagrams of quasi-binary polymer systems with *LCST/UCST* spinodals and hour-glass cloud-point curves

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Mumby, S.J.; Qian, C; Eichinger, B.E.; POLYMER, 1992, Volume 33, Number 23, 5105 - 5108

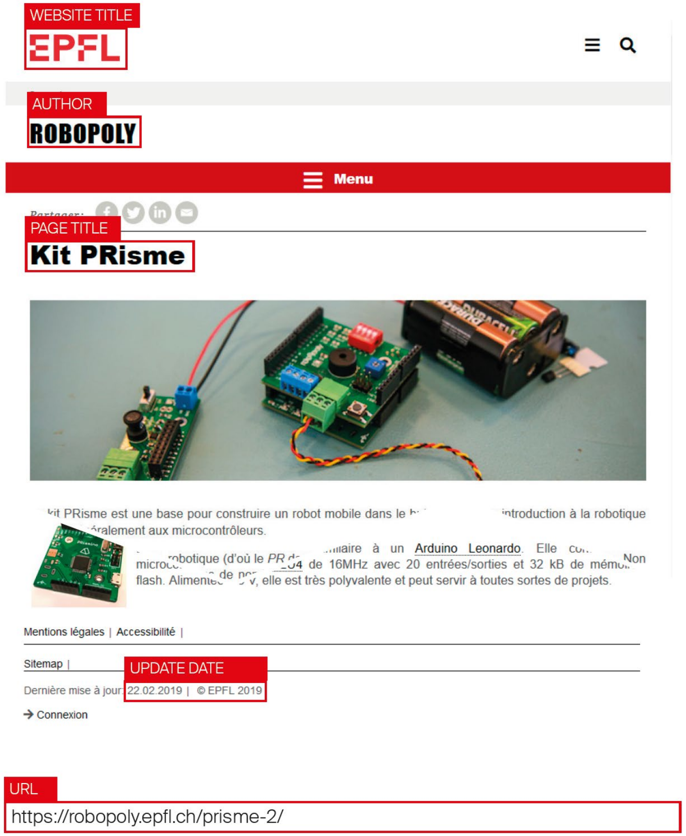
Instead of page numbers some journals assign an article number:

Exp.: Macromol. Rapid. Commun. 2023, 44, 2200529

Citation – Web Page

Web Pages

Page title
Author(s)
Article title
Web site title
URL + access date



Kit Prisme, Robopoly, EPFL
https://robopoly.epfl.ch/prisme-2/
(accessed Oct 28, 2019).

Artificial Intelligence

use AI tools in constructive ways **check for veracity and stay critical**

being able to take full responsibility for one's own written work

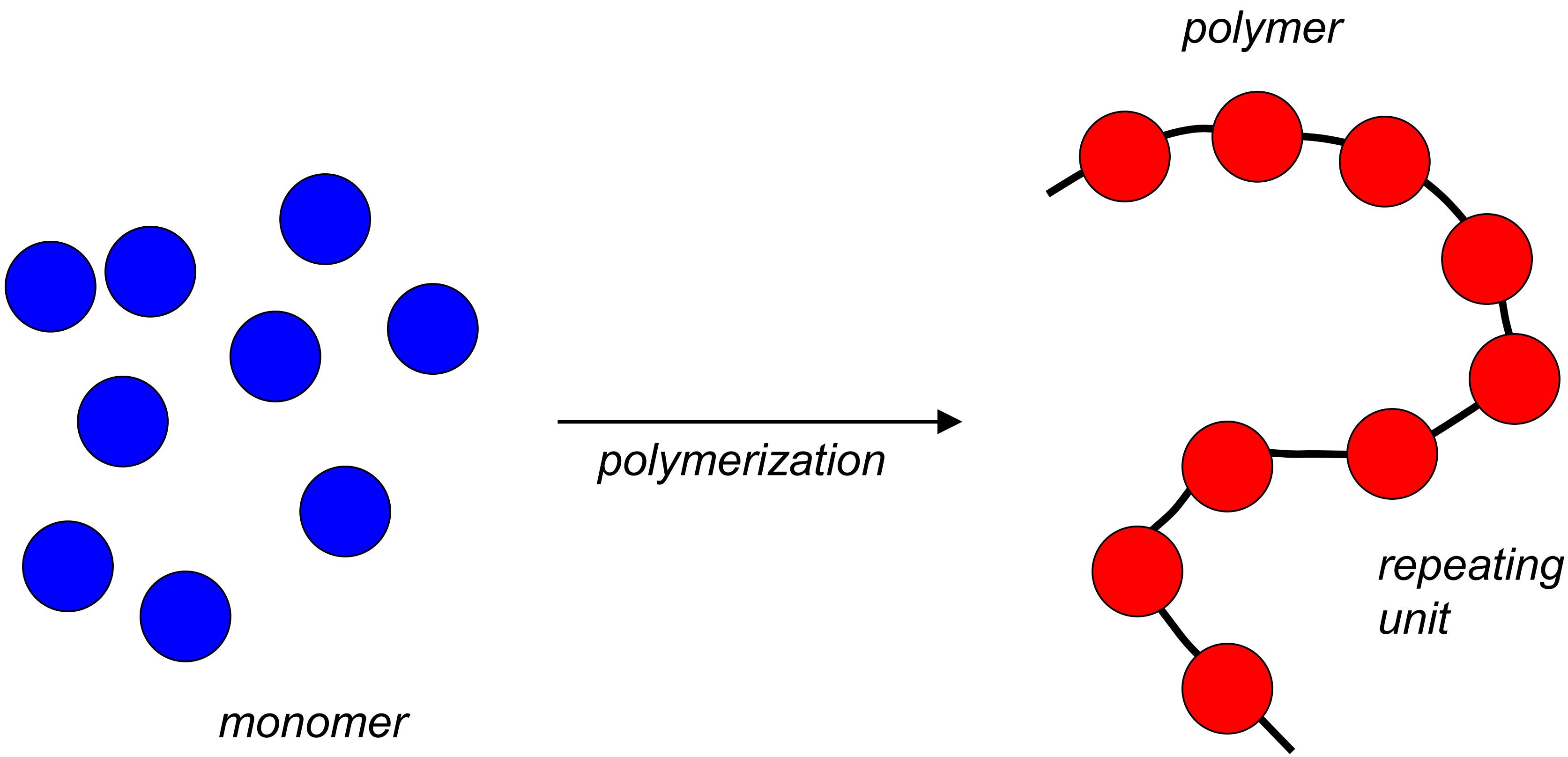
When citing AI-based tools, the following elements must be included:

• Title: for text, image, and multimedia generation tools, the prompt (i.e., user input) serves as
the title. For particularly long prompts, list only the beginning of the prompt.
• Name and version of the tool
• Publisher (company, organization or person who provided or programmed the tool)
• Date of content generation
• Location (address / URL of the tool)

AI tool X was used to improve the grammar of the text and make it more understandable or tool Y was used to generate an illustration

Plagiarism: Some responses from ChatGPT may resemble existing content, and without proper attribution, it could be considered plagiarism if presented as original work.

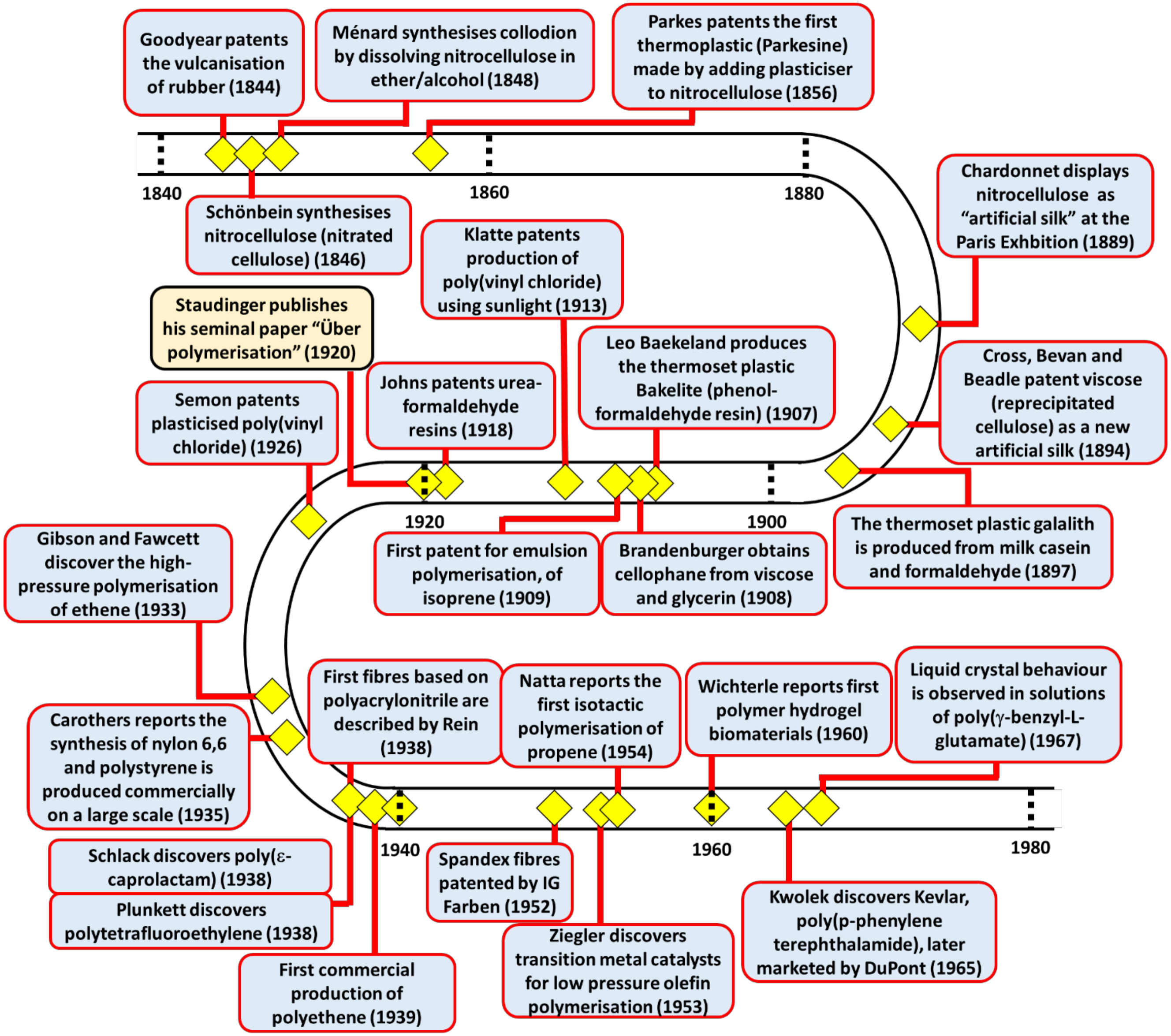
What are Polymers?



Degree of polymerization = number of repeat units

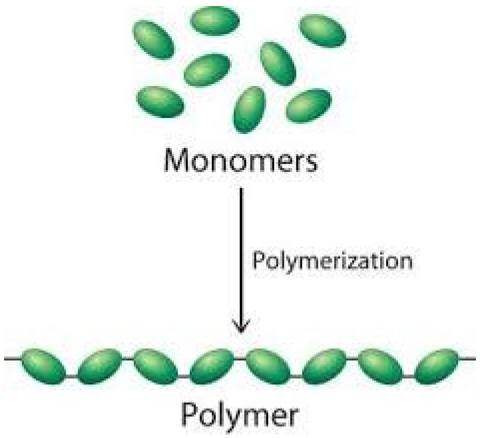
Molecular weight = [number of repeat units] x $[\text{molecular weight}]_{\text{repeat unit}}$

History

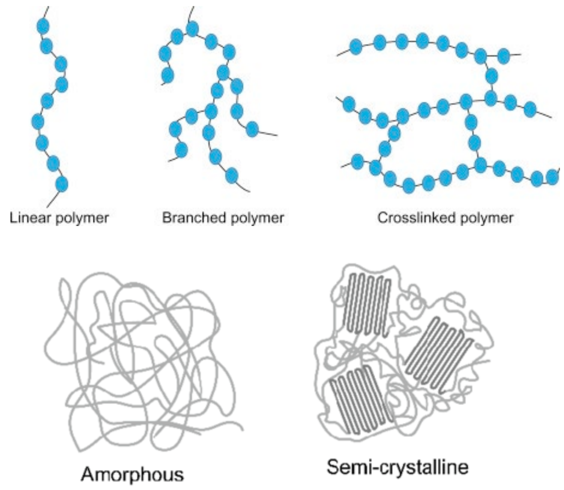

Goodyear patents the vulcanisation of rubber (1844)
Ménard synthesises collodion by dissolving nitrocellulose in ether/alcohol (1848)
Parkes patents the first thermoplastic (Parkesine) made by adding plasticiser to nitrocellulose (1856)
1840
1860
1880
Schönbein synthesises nitrocellulose (nitrated cellulose) (1846)
Chardonnet displays nitrocellulose as "artificial silk" at the Paris Exhbition (1889)
Klatte patents production of poly(vinyl chloride) using sunlight (1913)
Staudinger publishes his seminal paper "Über polymerisation" (1920)
Leo Baekeland produces the thermoset plastic Bakelite (phenol-formaldehyde resin) (1907)
Cross, Bevan and Beadle patent viscose (reprecipitated cellulose) as a new artificial silk (1894)
Johns patents urea-formaldehyde resins (1918)
Semon patents plasticised poly(vinyl chloride) (1926)
1920
1900
The thermoset plastic galalith is produced from milk casein and formaldehyde (1897)
Gibson and Fawcett discover the high-pressure polymerisation of ethene (1933)
First patent for emulsion polymerisation, of isoprene (1909)
Brandenburger obtains cellophane from viscose and glycerin (1908)
First fibres based on polyacrylonitrile are described by Rein (1938)
Natta reports the first isotactic polymerisation of propene (1954)
Wichterle reports first polymer hydrogel biomaterials (1960)
Liquid crystal behaviour is observed in solutions of poly(γ-benzyl-L-glutamate) (1967)
Carothers reports the synthesis of nylon 6,6 and polystyrene is produced commercially on a large scale (1935)
1940
1960
1980
Schlack discovers poly(ε-caprolactam) (1938)
Plunkett discovers polytetrafluoroethylene (1938)
Spandex fibres patented by IG Farben (1952)
Ziegler discovers transition metal catalysts for low pressure olefin polymerisation (1953)
Kwolek discovers Kevlar, poly(p-phenylene terephthalamide), later marketed by DuPont (1965)
First commercial production of polyethene (1939)

Polymer Science

How to make polymers



How do they arrange and behave



Soft matter by self-assembly

Polymer chemistry
Harm-Anton Klok

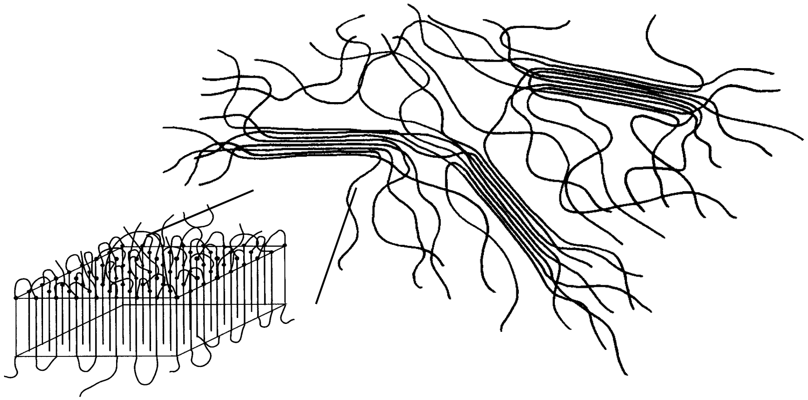
Organic- electronic materials
Holger Frauenrath

Soft Matter
Esther Amstad

Classification of Polymers

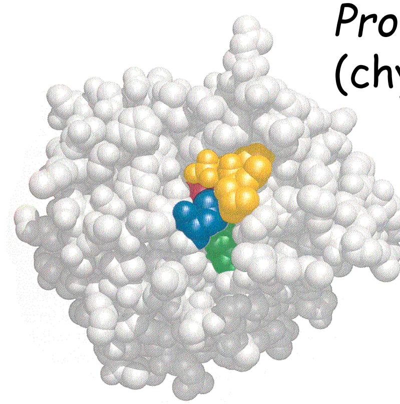
Synthetic Polymers

Polyethylene (semi-crystalline)

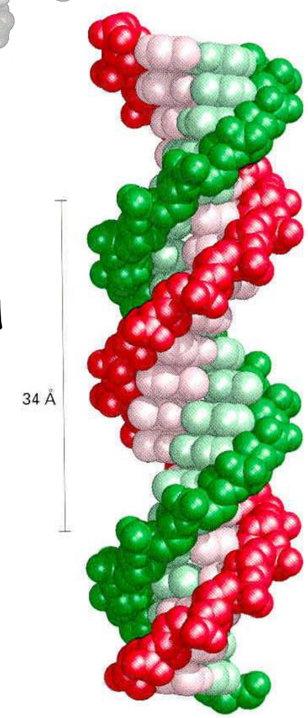


Biological Polymers

Proteins (chymotrypsin)



DNA



1. Classification of polymers

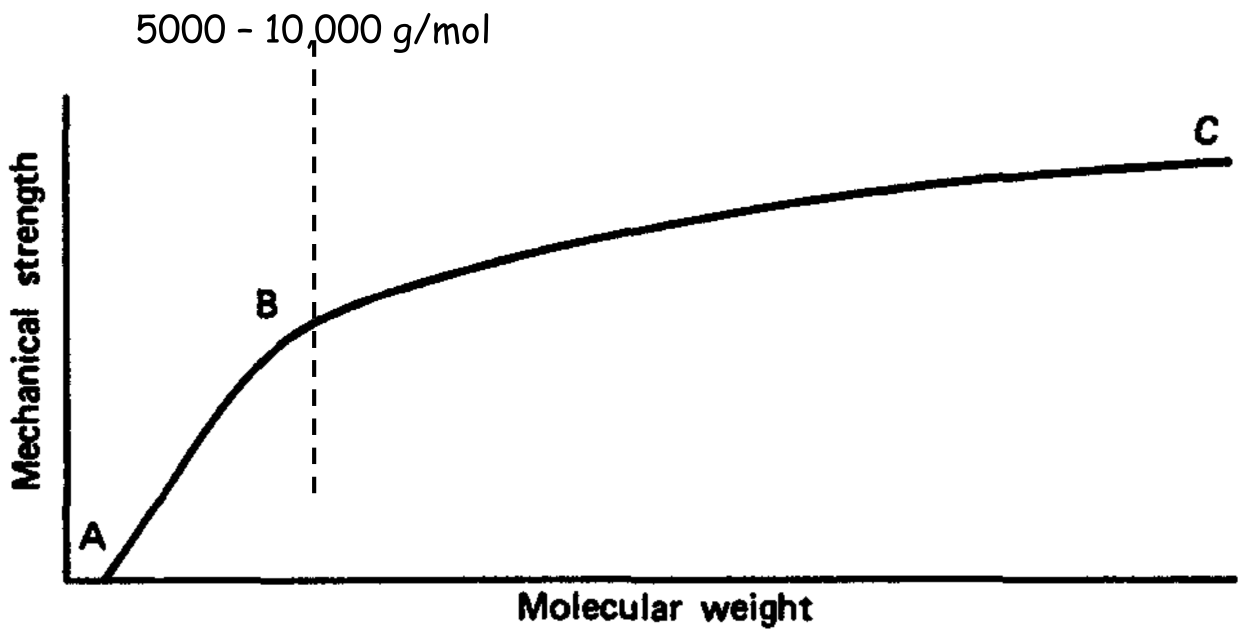
   Composition and architecture
   Chemical structure
   Polymerization mechanism
   Physical and mechanical properties

2. Properties of polymer chains

   Molecular weight and molecular weight distribution
   Conformation of the polymer chain in space
   Configuration of the polymer chain

3. Nomenclature of polymers

Molecular Weight



A: There is a minimum molecular weight required for a polymer to have a certain property
B: Critical molecular weight; strength increases fast until this point; minimum useful molecular weight typically 5.000 – 10.000
C: Limiting value

The desired polymer molecular weight is often a compromise in order to meet particular materials demands without overly sacrifying other properties

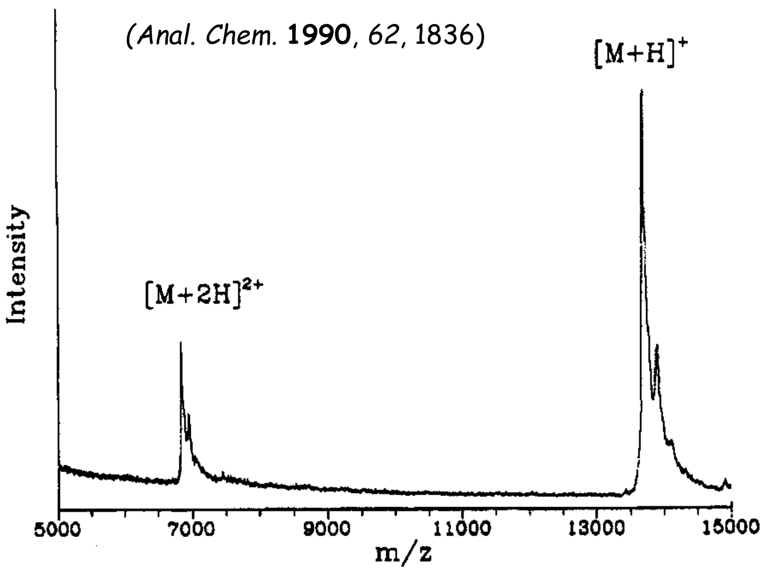
Synthetic Polymers are Mixtures!

- Due to statistical variations in the polymerization process, polymers even in their purest form, are usually mixtures of molecules of different molecular weights
- Both the average molecular weight and the molecular weight distribution are needed to fully characterize a polymer

MALDI TOF mass spectra of a natural polymer (protein) vs. that of a synthetic polymer

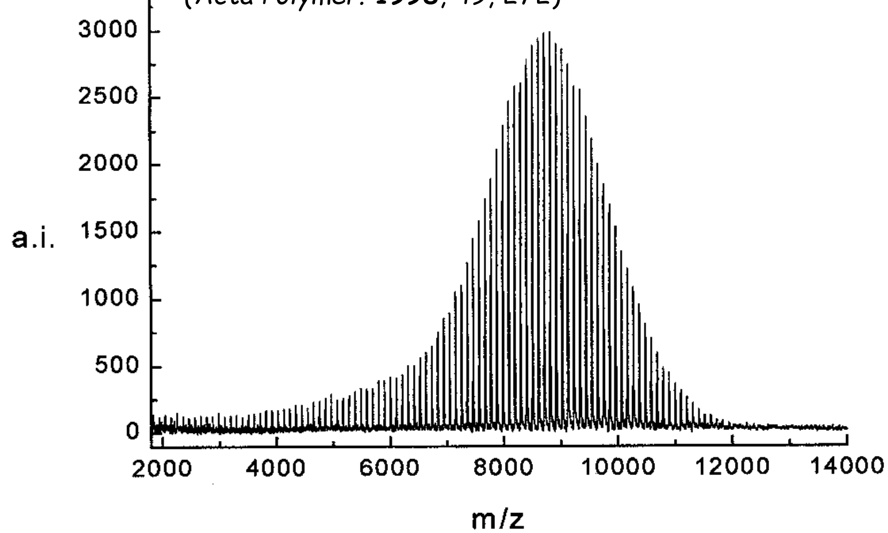
Ribonuclease A:

(Anal. Chem. **1990**, *62*, 1836)



Polystyrene (M_n = 9000 Da):

(Acta Polymer. **1998**, *49*, 272)



Polymer Molecular Weights

Problem: different techniques yield different molecular weights

1. **Number-average molecular weight (M_n)**

   M_n determined by methods that count the number of polymer molecules in a sample. Methods rely on colligative properties such as vapor pressure lowering, freezing point depression etc.

   Defined as: $$\overline{M_n} = \sum_i x_i M_i = \frac{\sum_i n_i M_i}{\sum_i n_i} = \frac{\sum_i c_i M_i}{\sum_i \frac{c_i}{M_i}}$$

   n_i is the number of moles whose weight is M_i.
   x_i is the mole fraction of molecules of size M_i
   c_i is the mass concentration $c_i = \frac{c_i M_i}{volume}$

2. Weight-average molecular weight (M_w)

M_w is obtained from light scattering, which is greater for larger-sized molecules than for smaller sized molecules.

Defined as: $$\overline{M_w} = \sum_i w_i M_i$$

where w_i is the weight fraction of molecules whose weight is M_i

Alternatively: $$\overline{M_w} = \frac{\sum_i c_i M_i}{\sum_i c_i} = \frac{\sum_i c_i M_i}{c} = \frac{\sum_i n_i M_i^2}{\sum_i n_i M_i}$$

where c_i is the weight concentration of M_i molecules, c is the total weight concentration of all the polymer molecules, and:

$$w_i = \frac{c_i}{c} \qquad c_i = n_i M_i \qquad c = \sum_i c_i = \sum_i n_i M_i$$

3. Viscosity-average molecular weight (*M_v*)

Solution viscosity does not measure M_w since the exact dependence of solution viscosity is different from light scattering

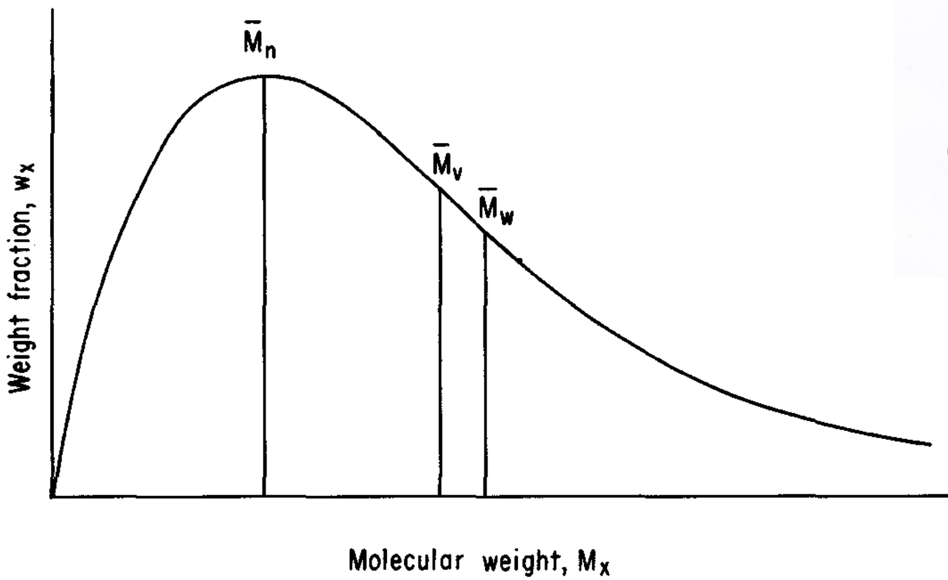
Defined as: $$\overline{M_v} = \left[\sum_i w_i M_i^a\right]^{1/a} = \left[\frac{\sum_i n_i M_i^{a+1}}{\sum_i n_i M_i}\right]^{1/a}$$

with a = 0.5-0.9.

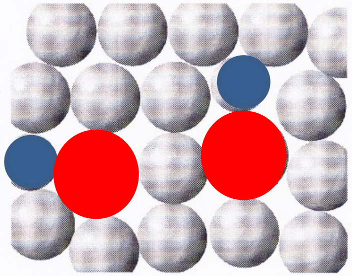
The **constant *a*** depends on the hydrodynamic volume of the polymer and the effective volume of the solvated polymer molecule in solution, and varies with polymer, solvent and temperature

note: $M_v = M_w$ if a= 1

Average Molecular Weights: M_n, M_v and M_w

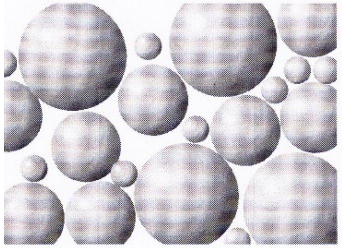


Distribution of molecular weights in a typical polymer sample.



n_i	M_i	$n_i \cdot M_i$	$n_i \cdot M_i^2$	$n_i \cdot M_i^3$
100	1,76	176	309,76	545,2
800	1,15	920	1058	1216,7
100	0,52	52	27,04	14,1
N=1000		1148	1394,8	1776

$M_n = \mu_1$	1,15
$M_w = \mu_2/\mu_1$	1,21
$M_z = \mu_3/\mu_2$	1,55
$\boldsymbol{U = M_w/M_n - 1}$	**0,05**



n_i	M_i	$n_i \cdot M_i$	$n_i \cdot M_i^2$	$n_i \cdot M_i^3$
200	4,19	838	3511,2	14712
400	1,15	460	529	608,4
400	0,07	28	2	0,14
N=1000		1326	4042,2	15320,5

$M_n = \mu_1$	1,33
$M_w = \mu_2/\mu_1$	3,0
$M_z = \mu_3/\mu_2$	3,79
$\boldsymbol{U = M_w/M_n - 1}$	**1,26**

- M_v and M_w are usually quite close (within 10-20%)
- M_n is biased towards the low molecular weight fraction
- M_w is biased towards the higher molecular weight fraction
- M_w/M_n depends on the breadth of the distribution curve and is useful as a measure of the polydispersity in a polymer

Classification by Composition

Homopolymers: polymers prepared from a single monomer (A)

Copolymers: polymers prepared from ≥ 2 monomers (A and B)

random: AABABBAAABAB

alternating: ABABABABABABA

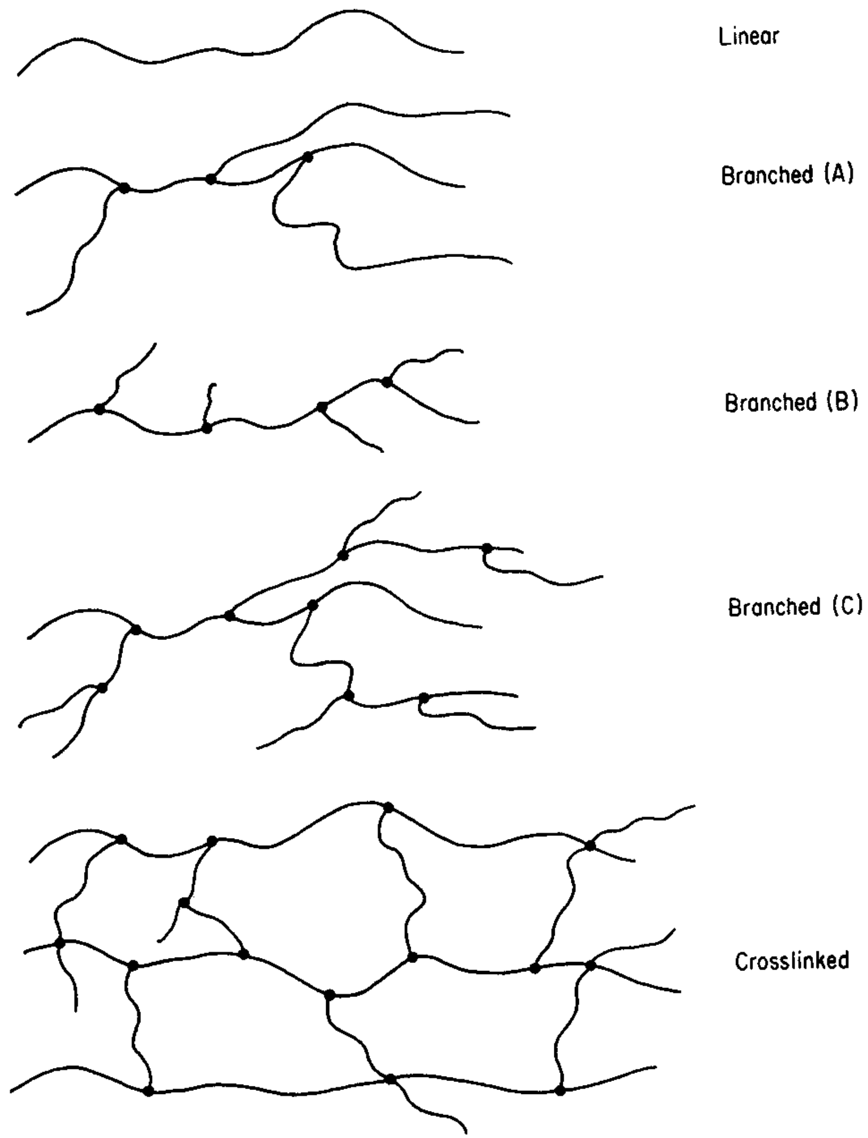
block: AAAABBBB

AAAABBBBAAAA

AAAABBBBCCCC

graft:
```
AAAAAAAAAAAA
      B
      B
      B
      B
```

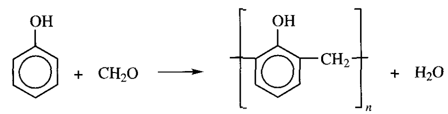
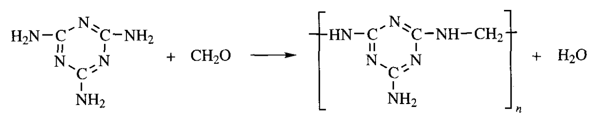
Classification by Architecture



Classification by Chemical Structure

Condensation Polymers

TABLE 1-1 Typical Condensation Polymers

Type	Characteristic Linkage	Polymerization Reaction
Polyamide	–NH–CO–	$\mathrm{H_2N{-}R{-}NH_2 + HO_2C{-}R'{-}CO_2H \longrightarrow H{+}NH{-}R{-}NHCO{-}R'{-}CO{+}_nOH + H_2O}$ $\mathrm{H_2N{-}R{-}NH_2 + ClCO{-}R'{-}COCl \longrightarrow H{+}NH{-}R{-}NHCO{-}R'{-}CO{+}_nCl + HCl}$ $\mathrm{H_2N{-}R{-}CO_2H \longrightarrow H{+}NH{-}R{-}CO{+}_nOH + H_2O}$
Protein, wool, silk	–NH–CO–	Naturally occurring polypeptide polymers; degradable to mixtures of different amino acids. $\mathrm{H{+}NH{-}R{-}CONH{-}R'{-}CO{+}_nOH + H_2O \longrightarrow H_2N{-}R{-}CO_2H + H_2N{-}R'{-}CO_2H}$
Polyester	–CO–O–	$\mathrm{HO{-}R{-}OH + HO_2C{-}R'{-}CO_2H \longrightarrow H{+}O{-}R{-}OCO{-}R'{-}CO{+}_nOH + H_2O}$ $\mathrm{HO{-}R{-}OH + R''O_2C{-}R'{-}CO_2R'' \longrightarrow H{+}O{-}R{-}OCO{-}R'{-}CO{+}_nOH + R''OH}$ $\mathrm{HO{-}R{-}CO_2H \longrightarrow H{+}O{-}R{-}CO{+}_nOH + H_2O}$
Polyurethane	–O–CO–NH–	$\mathrm{HO{-}R{-}OH + OCN{-}R'{-}NCO \longrightarrow {+}O{-}R{-}OCO{-}NH{-}R'{-}NH{-}CO{+}_n}$
Polysiloxane	–Si–O–	$\mathrm{Cl{-}SiR_2{-}Cl \xrightarrow[-HCl]{H_2O} HO{-}SiR_2{-}OH \longrightarrow H{+}O{-}SiR_2{+}_nOH + H_2O}$
Phenol–formaldehyde	–Ar–CH₂–	
Urea–formaldehyde	–NH–CH₂–	$\mathrm{H_2N{-}CO{-}NH_2 + CH_2O \longrightarrow {+}HN{-}CO{-}NH{-}CH_2{+}_n + H_2O}$
Melamine–formaldehyde	–NH–CH₂–	
Polysulfide	$\mathrm{-S_m-}$	$\mathrm{Cl{-}R{-}Cl + Na_2S_m \longrightarrow {+}S_m{-}R{+}_n + NaCl}$
Polyacetal	$\mathrm{-O{-}CH(R){-}O-}$	$\mathrm{R{-}CHO + HO{-}R'{-}OH \longrightarrow {+}O{-}R'{-}OCHR{+}_n + H_2O}$

Addition Polymers

TABLE 1-2 Typical Addition Polymers

Polymer	Monomer	Repeating Unit
Polyethylene	$\mathrm{CH_2{=}CH_2}$	$\mathrm{-CH_2{-}CH_2-}$
Polyisobutylene	$\mathrm{CH_2{=}C(CH_3)_2}$	$\mathrm{-CH_2{-}C(CH_3)_2-}$
Polyacrylonitrile	$\mathrm{CH_2{=}CH{-}CN}$	$\mathrm{-CH_2{-}CH(CN)-}$
Poly(vinyl chloride)	$\mathrm{CH_2{=}CH{-}Cl}$	$\mathrm{-CH_2{-}CH(Cl)-}$
Polystyrene	$\mathrm{CH_2{=}CH{-}\phi}$	$\mathrm{-CH_2{-}CH(\phi)-}$
Poly(methyl methacrylate)	$\mathrm{CH_2{=}C(CH_3)(CO_2CH_3)}$	$\mathrm{-CH_2{-}C(CH_3)(CO_2CH_3)-}$
Poly(vinyl acetate)	$\mathrm{CH_2{=}CH{-}OCOCH_3}$	$\mathrm{-CH_2{-}CH(OCOCH_3)-}$
Poly(vinylidene chloride)	$\mathrm{CH_2{=}CCl_2}$	$\mathrm{-CH_2{-}CCl_2-}$
Polytetrafluoroethylene	$\mathrm{CF_2{=}CF_2}$	$\mathrm{-CF_2{-}CF_2-}$
Polyisoprene (natural rubber)	$\mathrm{CH_2{=}C(CH_3){-}CH{=}CH_2}$	$\mathrm{-CH_2{-}C(CH_3){=}CH{-}CH_2-}$

A polymer is classified as a condensation polymer:

(i) if its synthesis involves the elimination of small molecules
(ii) if it contains functional groups as part of the polymer main chain
(iii) if its repeating unit lacks certain atoms that are present in the hypothetical monomer it is made of

A polymer that does not fulfill any of the above requirements is classified as an addition polymer

Classification by Polymerization Mechanism

Step Polymerization

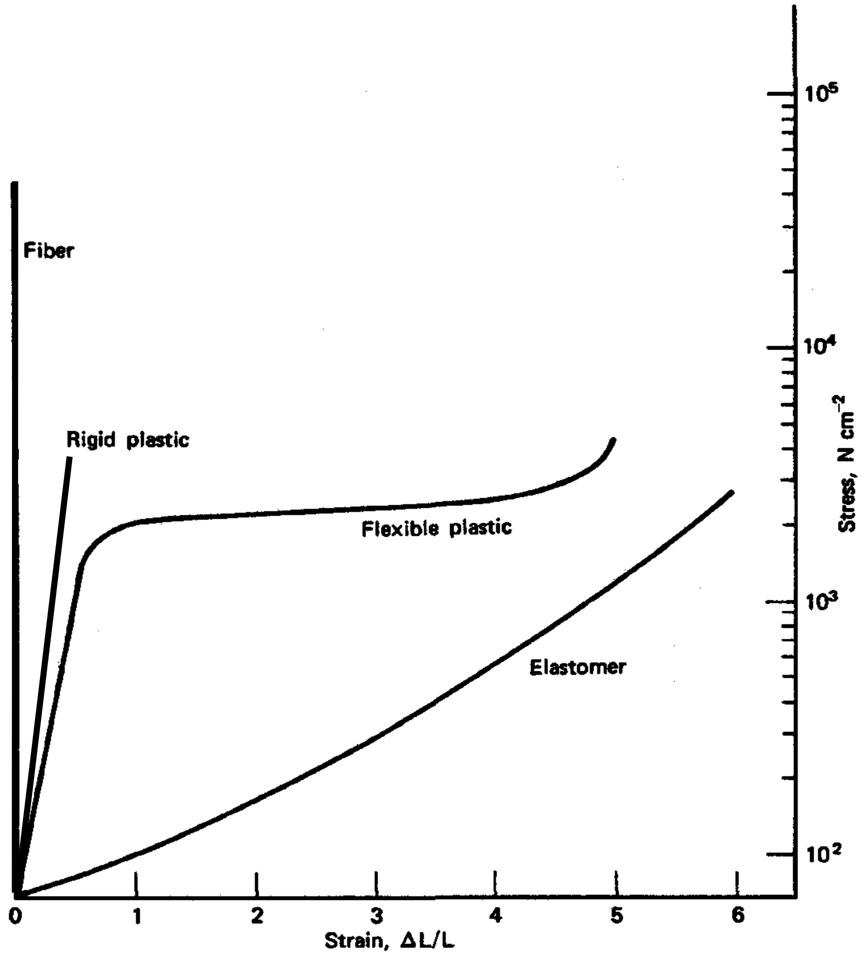
- Reaction occurs between any of the different sized species present in the reaction system
- Molecular weight increases relatively slowly with conversion

Chain Polymerization

- Monomer only reacts with the reactive center
- Chain growth is very rapid
- Monomer concentration decreases throughout the polymerization, while the number of high molecular weight polymer molecules increases
- The molecular weight of the polymer is relatively independent on monomer conversion (compared to a step polymerization)

Classification by Physical and Mechanical Properties

- example: mechanical properties: modulus (E)



$$\sigma = E\ \varepsilon$$

stress strain

E: resistance to deformation/stiffness

$E_{fiber} > E_{plastic} > E_{rubber}$

Classification by Physical and Mechanical Properties

- Classification by end-use:
  1. Plastics
  2. Fibers
  3. Rubbers (elastomers)
  4. Adhesives
  5. Coatings

Elastomers	Plastics	Fibers
Polyisoprene	Polyethylene	
Polyisobutylene	Polytetrafluoroethylene	
	Poly(methyl methacrylate)	
	Phenol–formaldehyde	
	Urea–formaldehyde	
	Melamine–formaldehyde	
←——Polystyrene	——→	
←——Poly(vinyl chloride)	——→	
←——Polyurethane	——→	
←——Polysiloxane	——→	
	←——Polyamide	——→
	←——Polyester	——→
	←——Cellulosics	——→
	←——Polypropene	——→
		Polyacrylonitrile

A given polymer may fall into more than one category !

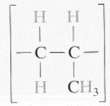
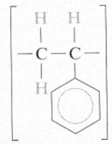
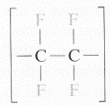
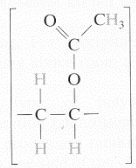
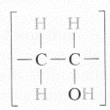
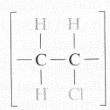
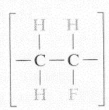
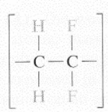
Appendix : Nomenclature of Polymers

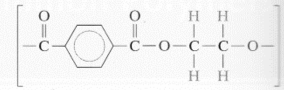
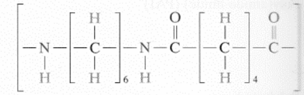
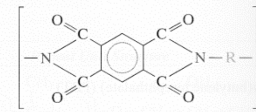
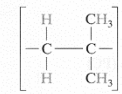
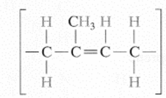
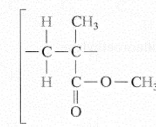
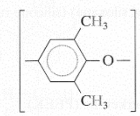
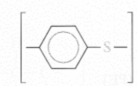
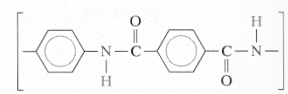
Polymer nomenclature leaves much to be desired .....

Different nomenclature systems:

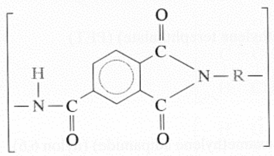
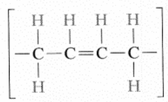
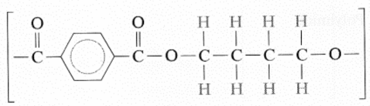
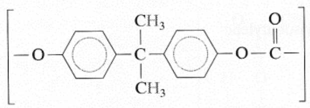
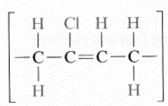
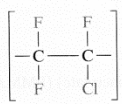
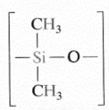
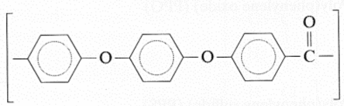
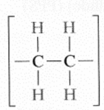
1. Nomenclature based on source
2. Nomenclature based on structure (non-IUPAC)
3. IUPAC structure-based nomenclature system
4. Tradenames and nonnames

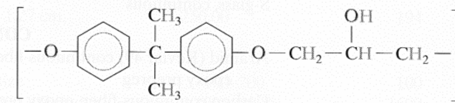
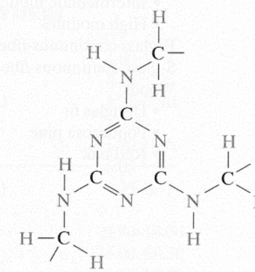
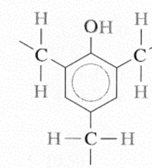
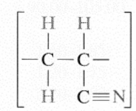
Appendix : Table of Common Polymers (1)

Chemical Name	*Repeat Unit Structure*
Polypropylene (PP)	
Polystyrene (PS)	
Polytetrafluoroethylene (PTFE)	
Poly(vinyl acetate) (PVAc)	
Poly(vinyl alcohol) (PVA)	
Poly(vinyl chloride) (PVC)	
Poly(vinyl fluoride) (PVF)	
Poly(vinylidene chloride) (PVDC)	
Poly(vinylidene fluoride) (PVDF)	

Chemical Name	*Repeat Unit Structure*
Poly(ethylene terephthalate) (PET)	
Poly(hexamethylene adipamide) (nylon 6,6)	
Polyimide	
Polyisobutylene	
cis-Polyisoprene (natural rubber)	
Poly(methyl methacrylate) (PMMA)	
Poly(phenylene oxide) (PPO)	
Poly(phenylene sulfide) (PPS)	
Poly(paraphenylene terephthalamide) (aramid)	

Appendix : Table of Common Polymers (2)

Chemical Name	Repeat Unit Structure
Poly(amide-imide) (PAI)	
Polybutadiene	
Poly(butylene terephthalate) (PBT)	
Polycarbonate (PC)	
Polychloroprene	
Polychlorotrifluoroethylene	
Poly(dimethyl siloxane) (silicone rubber)	
Polyetheretherketone (PEEK)	
Polyethylene (PE)	

Chemical Name	Repeat Unit Structure
Epoxy (diglycidyl ether of bisphenol A, DGEPA)	
Melamine-formaldehyde (melamine)	
Phenol-formaldehyde (phenolic)	
Polyacrylonitrile (PAN)	

Appendix : Nomenclature based on Source

- Polymers synthesized from a single monomer as in addition and ring-opening polymerizations
- Prefix „poly“ + name of the monomer without a space or hyphen

ethylene	→	polyethylene	
acetaldehyde	→	polyacetaldehyde	
3-methyl-1-pentene	→	poly(3-methyl-1-pentene)	Multiworded names or abnormally long names
vinyl chloride	→	poly(vinyl chloride)	
propylene oxide	→	poly(propylene oxide)	
chlorotrifluoroethylene	→	poly(chlorotrifluoroethylene)	
ε-caprolactam	→	poly(ε-caprolactam)	

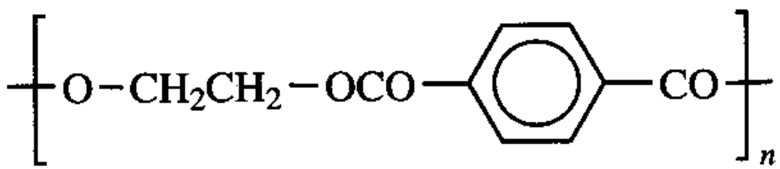
Appendix : Nomenclature based on structure (non-IUPAC)

- Polymers synthesized from two different monomers
- Prefix „poly“ followed without a space or hyphen by parentheses enclosing the name of the structural group attached to the parent compound (= ester amide, urethane, etc.)

$$\left[HN-(CH_2)_6-NHCO-(CH_2)_8-CO \right]_n$$

Poly(hexamethylene sebacamide)

IV



Poly(ethylene terephthalate)

V

$$\left[O-CH_2CH_2CH_2-OCONH-CH_2CH_2-NHCO \right]_n$$

Poly(trimethylene ethyleneurethane)

VI

Appendix : IUPAC Structure-based Nomenclature System

- Single-strand organic polymers
- Based on the selection of a preferred constitutional repeating unit (CRU)
- The CRU (also referred to as structural repeating unit) is the smallest possible repeating unit of the polymer
- Polymer name = poly(CRU) or poly[CRU]

Appendix :IUPAC rules for naming single-strand organic polymers:

1. The name of a polymer is the prefix *poly* followed in parentheses or brackets by the name of the CRU. The CRU is named by naming its subunits. Subunits are defined as the largest subunits that can be named by the IPUAC rules for small organic compounds.

2. The CRU is written from left to right beginning with the subunit of highest seniority and proceeding in the direction involving the shortest route to the subunit next in seniority.

3. The seniority of different types of subunits is heterocyclic rings > heteroatoms or acyclic subunits containing heteroatoms > carbocyclic rings > acyclic subunits containing only carbon. The presence of various types of atoms, groups of atoms, or rings that are not part of the main polymer chain but are substituents on the CRU do not affect this order of seniority.

4. For heterocyclic rings the seniority is a ring system having nitrogen in the ring > a ring system having a heteroatom other than nitrogen in the order of seniority defined by rule 5 below > a ring system having the greatest number of heteroatoms > a ring system having the largest individual ring > a ring system having the greatest variety of heteroatoms > a ring system having the greatest number of heteroatoms highest in the order given in rule 5.

5. For heteroatom(s) or acyclic subunits containing heteroatom(s), the order of decreasing priority is O, S, Se, Te, N, P, As, Sb, Bi, Si, Ge, Sn, Pb, B, Hg. (Any heteroatom has higher seniority than carbon—rule 3.) The seniority of other heteroatoms within this order is determined from their positions in the periodic table.

6. For carbocyclic rings the seniority is a ring system having the greatest number of rings > the ring system having the largest individual ring > the ring system having the greatest number of atoms common to its rings.

7. For a given carbocyclic or heterocyclic ring system: (a) when rings differ only in degree of unsaturation, seniority increases with degree of unsaturation; (b) for the same ring system, seniority is higher for the ring system having the lowest location number (referred to as *locant*), which designates the first point of difference for ring junctions.

8. These orders of seniority are superseded by the requirement of minimizing the number of free valences in the CRU, that is, the CRU should be a bivalent unit wherever possible.

9. Where there is a choice subunits should be oriented so that the lowest locant results for substituents.

Appendix: Tradenames and nonnames

Nylon: Polyamides from unsubstituted, nonbranched aliphatic monomers

nylon 6,6 poly(hexamethylene adipamide)
nylon 6,10 poly(hexamethylene sebacamide)

first number: number of methylene groups in diamine portion
second number: number of carbon atoms in diacyl portion

Polyamides from single monomers are denoted by a single number representing the number of carbon atoms in the repeating unit
e.g. nylon 6, poly(ε-caprolactam) or poly(6-amino caproic acid)