

Arthur E. Woodward

# Atlas of Polymer Morphology

with 442 Figures and 4 Tables



Hanser Publishers, Munich Vienna New York

---

Distributed in the United States of America by  
Oxford University Press, New York  
and in Canada by  
Oxford University Press, Canada

# CONTENTS

---

<b>Chapter I</b>	<b>Polymer Science Introduction</b>	1
	References	8
<b>Chapter II</b>	<b>Sample Preparation Techniques and Investigative Methods</b>	13
	References	19
<b>Chapter III</b>	<b>Polymers Crystallized from Solution</b>	20
A.	Single Lamellas	20
1.	Polyethylene	22
2.	Polyoxymethylene	23
3.	Polypropylene	23
4.	Polybutene	23
5.	Poly(4-methyl pentene-1)	23
6.	Poly [bis(trifluoroethoxy)phosphazene]	24
7.	Poly [bis(phenoxy)phosphazene]	24
8.	Poly(aryl ether ether ketone)	24
9.	Poly(p-phenylene sulfide)	24
10.	Poly(tetramethyl-p-silphenylene siloxane)	24
11.	trans-1,4-Polyisoprene	24
12.	Poly(vinylidene fluoride)	25
13.	Cellulose Triacetate	25
14.	Amylose	25
B.	Multilamellar Structures	25
1.	trans-1,4-Polyisoprene	27
2.	Polyethylene and Ethylene/Vinyl Acetate Copolymers	28
3.	Poly(aryl ether ether ketone)	29
4.	Poly(1,4- $\beta$ -D-mannose)	29
5.	Isotactic Polypropylene	30
6.	Isotactic Polystyrene	30
7.	Poly(docosyl acrylate)	30
	References	31
	Figures	32
<b>Chapter IV</b>	<b>Crystallization from the Melt</b>	88
A.	General Considerations	88
B.	Single Lamellas	91
C.	Extended Chain Structures	92
D.	Folded Chain Multilamellar Structures	93
1.	Polyethylene	93
2.	cis-1,4-Polyisoprene	95

3. Poly(aryl ether ether ketone) . . . . .	95
4. Poly(p-phenylene sulfide) . . . . .	95
5. Isotactic Polypropylene . . . . .	96
6. Isotactic Polystyrene . . . . .	97
7. Poly(vinylidene fluoride) . . . . .	97
E. Thermal Treatments . . . . .	98
References . . . . .	99
Figures . . . . .	100
<b>Chapter V Crystallization during Polymerization . . . . .</b>	173
1. Substituted Polydiacetylenes . . . . .	173
2. Polytetrafluoroethylene . . . . .	174
3. Poly(3-methyl thiophene) and Ionized Poly(3-methyl thiophene) . . . . .	174
4. Cellulose . . . . .	175
Figures . . . . .	176
<b>Chapter VI Block Copolymers . . . . .</b>	189
A. General Comments . . . . .	189
B. Specific Systems . . . . .	193
1. Polystyrene/Polyisoprene Diblock Copolymers . . . . .	193
2. Polystyrene-rich/Polyisoprene-rich Diblock Copolymer . . . . .	194
3. Multiarm Polyisoprene/Polystyrene Star Block Copolymer . . . . .	194
4. Polystyrene/Styrene-Butadiene Random Copolymer/Polybutadiene Block Copolymers . . . . .	194
5. Triblock Copolymers of Polystyrene/Polybutadiene/Poly(4-vinylpyridine) . . . . .	195
6. Polystyrene/Poly(ethylene oxide) Diblock Copolymers . . . . .	195
7. Poly[(tetramethyl-p-silphenylene) siloxane]/Poly(dimethyl siloxane) Diblock Copolymers . . . . .	196
8. (trans-1,4-Polyisoprene)/Epoxidized (trans-1,4-Polyisoprene) Segmented Block Copolymer . . . . .	196
9. Segmented Copolymers of Polyamide 12 and Poly(tetramethylene oxide) . . . . .	196
References . . . . .	197
Figures . . . . .	198
<b>Chapter VII Liquid Crystalline Polymers . . . . .</b>	216
A. General Considerations . . . . .	216
B. Specific Systems . . . . .	219
1. Copolyester of Methyl Hydroquinone, Pyrocatechol and Terephthalic Acid . . . . .	219
2. Copolyester Prepared by Transesterification of Poly(ethylene-1,2-diphenoxylethane-p,p'-dicarboxylate) with p-Acetoxybenzoic Acid . . . . .	219

3. Poly(3-methylphenylazophenylmethine) . . . . .	219
4. Poly( $\beta$ -thioesters) . . . . .	219
5. Polyesters from p-Terphenyl-4,4" dicarboxylic Acid . . . . .	219
6. Poly(4'-cyanobiphenyl-4-oxy-6-hexyl acrylate) . .	220
7. Copolyesters Containing Main-Chain 2,6-Naphthyl and 1,4-Phenyl Groups . . . . .	220
8. Poly(bis-trifluoroethoxyphosphazene) . . . . .	221
9. Solutions of Hydroxypropyl Cellulose and Derivatives . . . . .	221
10. Solutions of Poly(p-phenylene benzobisthiazole) and Polybenzamide . . . . .	221
11. Block Copolymer/Solvent Systems . . . . .	221
References . . . . .	222
Figures . . . . .	226
<b>Chapter VIII Processing Effects . . . . .</b>	<b>263</b>
A. Introduction . . . . .	263
B. Specific Systems Illustrated . . . . .	263
1. Crystallization in a Longitudinal Flow Field . . . . .	263
2. Crystallization from the Melt Under Torsional Flow Conditions . . . . .	264
3. Melt Crystallization During Capillary Extrusion . . . . .	265
4. Extrusion of Liquid Crystalline Polymers . . . . .	266
5. Shear Oriented Thermotropic Polymers . . . . .	269
6. Oriented Lyotropic Polyamides . . . . .	269
7. Segmented Copolymers Melt Crystallized with Shearing . . . . .	269
8. Orientation by Drawing, Rolling and Annealing . . . . .	270
9. Compression and Injection Molded Samples . . . . .	270
10. Polymer Foams . . . . .	271
References . . . . .	271
Figures . . . . .	272
<b>Chapter IX Polymer Blends and Composites . . . . .</b>	<b>305</b>
A. Blends . . . . .	305
1. Polystyrene/Poly(methyl methacrylate) . . . . .	306
2. Polystyrene/Poly(bromostyrene) . . . . .	306
3. Polystyrene/Polybutadiene Block-Copolymer with Polybutadiene and/or Polystyrene . . . . .	307
4. Polystyrene/Polyisoprene Block Copolymers with Polyisoprene and/or Polystyrene . . . . .	307
5. ABS with Styrene/Maleic Anhydride/(Methyl methacrylate) Terpolymer, with Polycarbonate and Styrene/Maleic Anhydride/(Methyl methacrylate) or with Rubber Modified Poly(norbornene nitrile) . .	308
6. Amine Terminated Butadiene-Acrylonitrile/Cured Epoxy Resin . . . . .	309

7. Poly(diphenyl ether sulfone) and Multifunctional Epoxy Resins . . . . .	309
8. Poly(methyl methacrylate) and poly(butyl acrylate) . . . . .	310
9. Poly(ethylene oxide) and Poly(methyl methacrylate) . . . . .	310
10. Polyamide-6 and Ethylene/Vinyl Acetate Copolymer . . . . .	310
11. Polycarbonate and an Aromatic Copolyester . . . . .	310
12. Linear and Branched Polyethylene . . . . .	310
13. Polyethylene and Isotactic Polypropylene . . . . .	311
14. Isotactic and Atactic Polypropylenes . . . . .	311
15. Isotactic Polypropylene and Ethylene/Propylene Rubber . . . . .	312
B. Polymer Composites . . . . .	312
Polyethylene and Inorganic Fillers . . . . .	314
Figures . . . . .	316
<b>Chapter X Effects of Mechanical Deformation</b> . . . . .	362
A. General Comments . . . . .	362
B. Specific Systems Investigated . . . . .	364
1. As Polymerized Films . . . . .	364
2. Solution Crystallized Polymers . . . . .	365
3. Solution Cast Polymer Films . . . . .	366
4. Melt Crystallized Polymers . . . . .	367
5. Drawn Monofilaments . . . . .	367
6. Thermoplastic Systems: Polystyrene . . . . .	368
7. Thermoplastic Systems: Triblock Copolymer . . . . .	368
8. Thermoplastic Systems: Polymer Blends . . . . .	368
Figures . . . . .	370
<b>Chapter XI Fracture</b> . . . . .	417
A. General Observations . . . . .	417
B. Specific Systems . . . . .	418
1. Amorphous Thermoplastics . . . . .	418
2. Partially Crystalline Polymers . . . . .	420
3. Amorphous Networks . . . . .	421
4. Polymer Composites . . . . .	422
Figures . . . . .	424
<b>Chapter XII Effects of Chemicals and Other Agents</b> . . . . .	469
A. General Comments . . . . .	469
B. Effects of Solvents and Solvent Vapors . . . . .	470
C. Effects of Reactive Environments . . . . .	472
D. Ion Etching and Electron Irradiation Effects . . . . .	474
References . . . . .	475
Figures . . . . .	476
<b>Subject Index</b> . . . . .	527