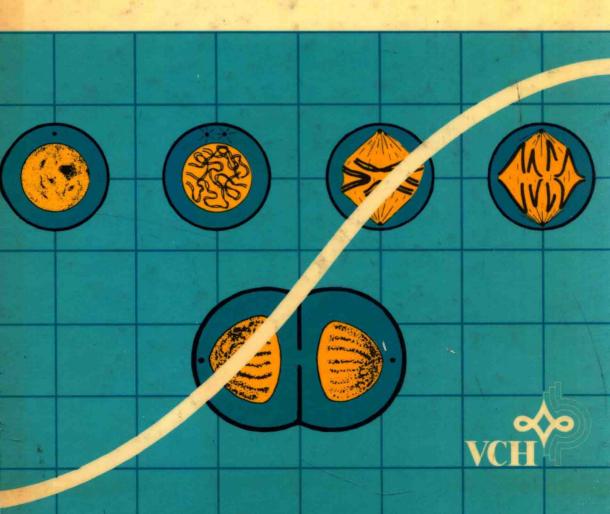
# Fundamentals of Biotechnology

Edited by P. Präve, U. Faust, W. Sittig, D. A. Sukatsch



## Fundamentals of Biotechnology

Edited by Paul Präve, Uwe Faust, Wolfgang Sittig and Dieter A. Sukatsch



Original Title: Handbuch der Biotechnologie

Copyright 1982 by Akademische Verlagsgesellschaft, D-6200 Wiesbaden

Translated by B. J. Hazzard

Editorial Director: Dr. Hans-F. Ebel

Production Manager: Heidi Lenz

Library of Congress Card No. 87-10604

Deutsche Bibliothek, Cataloguing-in-Publication Data

Fundamentals of biotechnology / ed. by P. Präve ... [Transl. by B. J. Hazzard]. -

Weinheim; Deerfield Beach, FL: VCH, 1987.

Einheitssacht.: Handbuch der Biotechnologie (engl.)

ISBN 3-527-26144-3 (Weinheim);

ISBN 0-89573-224-6 (Deerfield Beach, FL)

NE: Präve, Paul [Hrsg.]; EST

© VCH Verlagsgesellschaft mbH, D-6940 Weinheim (Federal Republic of Germany), 1987

All rights reserved (including those of translation into other languages). No part of this book may be reproduced in any form – by photoprint, microfilm, or any other means – nor transmitted or translated into a machine language without written permission from the publishers. Registered names, trademarks,

etc. used in this book, even when not specifically marked as such, are not to be considered unprotected by law.

Composition and printing: Zechnersche Buchdruckerei, D-6720 Speyer Bookbinding: J. Schäffer OHG, D-6718 Grünstadt

Printed in the Federal Republic of Germany

### Fundamentals of Biotechnology

Edited by Präve/Faust/Sittig/Sukatsch



© VCH Verlagsgesellschaft mbH, D-6940 Weinheim (Federal Republic of Germany), 1987

Distribution:
VCH Verlagsgesellschaft, P.O. Box 1260/1280, D-6940 Weinheim (Federal Republic of Germany)
USA and Canada: VCH Publishers, Suite 909, 220 East 23rd Street, New York NY 10010-4606 (USA)

ISBN 3-527-26144-3 (VCH Verlagsgesellschaft)

ISBN 0-89573-224-6 (VCH Publishers)

#### Preface

Biotechnology covers a wealth of specialized disciplines which includes not only the new genetic engineering techniques but also old fermentation processes which our ancestors practised thousands of years ago. In recent years many exciting developments have taken place, and - especially in the eyes of the public - the field has gained greatly in importance. It took some time for the literature to catch up with the rapid progress being made both in university and industrial laboratories. One of the first books to give a comprehensive description of the entire field was a predecessor of the present book (published in Germany in 1982). The success of this book and the considerable interest shown by Englishspeaking colleagues have prompted us to prepare an English version. Fundamentals of Biotechnology is based on the second edition of the German book; the entire contents have been brought up to date and in part revised.

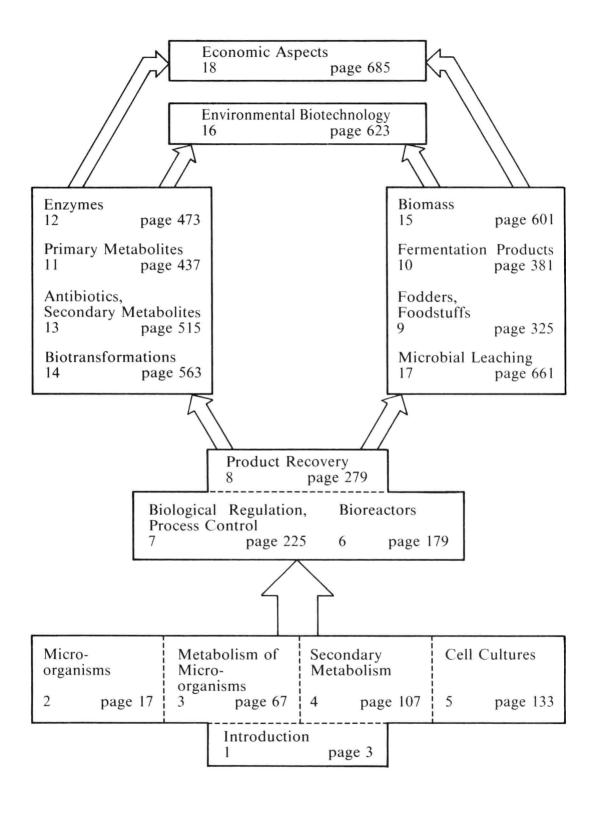
Fundamentals of Biotechnology is not only an advanced textbook but is intended for everyone who is interested in biotechnological questions. In a field involving people with widely different backgrounds – microbiologists, engineers, chemists and many others – it was our idea to provide colleagues with a

ready source of information. The different faces of biotechnology are presented by various authors. We have not attempted to suppress the individuality of the authors completely. Experience has shown us that this yields a coverage which is more vivid and provides a better view of specific subjects than if the editors had taken excessive pains to unify contributions. Chapters 1 to 8, which present the basic concepts of biotechnology, are followed by chapters dealing with special processes and products. Each chapter includes a detailed list of references. In the Appendix useful information on sources, products and biotechnological processes is collected. The extensive index will be especially appreciated by those wishing to use the book as a reference work.

We are indebted to Frau A. Christ for her invaluable assistance in the preparation of this book. To the translator, Mr B. J. Hazzard, we offer our special thanks for his careful translation of the German book and for his helpful comments. Finally, we wish to thank Dr I. Umminger for her painstaking editorial management and for compiling the index.

January 1987

The Editors



#### Contents

#### Part I Introduction

1	Biotechnology - History, Processes, and Products 3
1.1	Definition 4
1.2	Development of Biotechnology 4
1.2.1	Unconscious Use of Biotechnology:
	Processes in the Manufacture of Foodstuffs 4
1.2.2	Biotechnological Processes without
	Absolute Prohibition of Foreign
	Infections 8
1.2.3	Biotechnological Manufacture of
	Products with the Exclusion of
	Foreign Microbes 8
1.2.4	Application of Important Results of
	Basic Research to Biotechnology 9
1.3	General Observations of
	Biotechnological Processes 9
1.4	Importance of Biotechnology 12
1.5	Literature 14

#### Part II Fundamentals of Biotechnology

2

	improvement 1/
0.1	The state of the s
2.1	Introduction 18
2.2	Bacteria (Schizomycetes) 18
2.2.1	Definition of Terms 18
2.2.2	Classification 21
2.2.3	Bacteria of Biotechnological
	Importance 22
2.2.4	General Remarks on Cultivation,
	Maintenance, and Storage 22
2.3	Fungi (Mycophyta) 27
2.3.1	Definition of Terms 27
2.3.2.	Classification 32
2.3.3	Biotechnologically Important
	Fungi 42
2.3.4	General Remarks on Cultivation,
	Maintenance, and Storage 42
2.4	Strain Improvement 46
2.4.1	Selection 46
2.4.2	Selection with Subsequent
	Mutation 46
2.4.3	Selection and Mutation with
	Subsequent Recombination 48
2.4.4	Gene Manipulation 50
2.5	Literature 59

Literature 59

Microorganisms - Biology and Genetic Procedures for Strain

3	The Metabolism of Microorganisms 67	4	Secondary Metabolism 107
	organisms o/	4.1	Introduction 108
3.1	Introduction 68	4.2	Occurrence of Secondary Metabolites in Microorganisms 108
3.2	Basic Metabolism 68	4.3	Variations in the Secondary
3.2.1	Function of the Enzymes 69	4.3	Metabolism 111
3.2.2	Coenzymes and Prosthetic Groups	4.4	Special Chemical Groups and Basic
222	70	7.7	Intermediates in the Secondary
3.2.3	Hydrogen Transfer Reactions 71		Metabolism 112
3.2.4	Mechanisms of ATP Regeneration 71	4.4.1	Covalently Bound Chlorine or
3.2.5	Uptake of Substrates into the Cell		Bromine 112
	73	4.4.2	Unusual Nitrogen Compounds 113
3.2.6	Degradation of Carbon and Energy Sources 74	4.4.3	Unusual Compounds Containing Phosphorus 113
3.2.7	Synthesis of the Low-Molecular-	4.4.4	Unusual Organometallic Com-
3.2.7	Weight Constituents of the Cell 78		pounds 114
3.2.8	Synthesis of Macromolecular	4.4.5	Boron-Containing Metabolites 114
3.2.0	Constituents of the Cell 80	4.4.6	Unusual Amino Acids 114
3.2.9	Regulation 81	4.4.7	Unusual Ring Systems 114
3.2.10	Substrates of Microorganisms and	4.5	Function of Secondary
	Degradation Pathways 84		Metabolites 117
3.3	Assignment of the Most Important	4.5.1	Secondary Metabolism as Derailed
	Secretion Products to the Metabolic		Primary Metabolism 117
	Types of Microorganisms 92	4.5.2	Secondary Metabolites as
3.4	Metabolic Types 92		"Biochemical Appendices" 117
3.4.1	Basic Properties of Fermentative	4.5.3	Secondary Metabolites as Waste
	Organisms 93		Products, Shavings from an
3.4.2	Basic Properties of Organotrophic		Imperfectly Functioning Intermediate
	Aerobically Respiring Micro-		Metabolism 117
	organisms 96	4.5.4	Secondary Metabolites as Products
3.4.3	Basic Properties of Lithotrophic		of Detoxification Mechanisms 118
	Aerobically Respiring Bacteria 98	4.5.5	
3.4.4	Basic Properties of "Anaerobically		an Inhibited Growth 118
	Respiring" Bacteria 100	4.5.6	The Secondary Metabolism as a
3.4.5	1		Playing Field of Biochemical
	Organisms 102		Evolution 118
3.5	The Impulse to Research 103	4.6	Biogenesis and Biosynthesis of
3.6	Literature 104		Secondary Metabolites 120
3.6.1	Cited Literature 104	4.6.1	Polyketides 123
3.6.2	Further Reading 104	4.6.2	Amino Acids as Structural Units of Secondary Metabolites 126
		4.6.3	Sugars as Structural Units of Secondary Metabolites 129

4.6.4	Mevalonic Acid as a Structural Unit	6.3	Selection of the Reactor 186
	of Secondary Metabolites 129	6.3.1	Characteristics Predetermined by the
4.7	Biological Effects of Secondary		Nature of the Organism Used 186
	Metabolites Outside the Producing	6.3.2	Characteristics Predetermined by the
4.0	Cell 130		Properties of the Medium 187
4.8	Literature 130	6.3.3	Characteristics Predetermined
			by the Parameters of the Biochemical
		(24	Process 189
5	Plant and Animal Cell	6.3.4	Characteristics Predetermined by the
3	Culture 133	4.1	Site 189
	Culture 133	6.4	Submerged Reactors and their Characterization 189
c 1	Toward toward on 197	6.4.1	Power Input by Mechanically Moved
5.1	Introduction 134	0.4.1	Internal Devices 190
5.2	Plant Cell Cultures 134	6.4.2	Power Input by Liquid Circulation
5.2.1	General 134	0.4.2	with an External Pump 203
5.2.2	Work with Plant Cell Cultures 134	6.4.3	Power Input by Compressed Gas
5.2.3	Biotechnological Application 139	0.4.3	208
5.2.4	Agricultural Use of Plant Cell	6.5	Surface Reactors and their
5 2 5	Culture Technique 139 Use of Plant Cell Cultures in	0.5	Characterization 211
5.2.5	Industry 142	6.5.1	Solid Nutrient Substrates 211
526	Summary 149	6.5.2	Fluidized Bed Reactors 212
5.2.6 5.2.7	Literature: Plant Cell Cultures 149	6.5.3	Agitated Solid Bed Reactors 212
5.2.7	Animal Cell Cultures 153	6.5.4	Tray Reactors 212
5.3.1	General 153	6.5.5	Packed-bed Reactors 212
5.3.2	Experimental Work with Animal Cell	6.5.6	Film Reactors 213
0.0.4	Cultures 154	6.5.7	Immersing Surface Reactors 214
5.3.3	Technological Uses of Animal Cell	6.5.8	Immobilized Cells 214
0.0.0	Cultures 161	6.6	Comparison of Reactors 215
5.3.4	Prospects 172	6.7	Reactors in Industry 216
5.3.5	Literature: Animal Cell Cultures 173	6.7.1	Present State of the Art 216
		6.7.2	Trends of Further Development 216
		6.8	Practical Advice on the Choice of
			Reactors 216
6	Bioreactors 179	6.9	Literature 217
		6.10	Explanation of the Symbols 222
6.1	Introduction 180		
6.2	Basic Concepts 181		
6.2.1	Batch Operation 181	7	Biological Regulation and
6.2.2	"Extended Culture" Operation 181	,	
6.2.3	Continuous Operation 181		Process Control 225
6.2.4	Production of Heat During Cell		T
	Growth 183	7.1	Introduction 226
6.2.5	Stirring Power 183	7.2	Characteristics of the Biological
6.2.6	Oxygen Transfer 184		Control Cycle 234

8.4.5

8.4.6

299

Ion-exchange Processes and Adsorption with Adsorber Resins

Precipitation Reactions 302

7.2.1	Structure 234	8.5	Purification 303
7.2.2	Gene Expression 236	8.5.1	Crystallization 304
7.2.3	Regulation of Enzyme Activity 236	8.5.2	Chromatography 304
7.2.4	Relevant Process Parameters 242	8.6	Drying 312
7.3	Measurement Technique 242	8.6.1	Contact Dryers 313
7.3.1	Principles 242	8.6.2	Convection Dryers 314
7.3.2	Exemplary Measurement Tech-	8.6.3	Freeze-dryers 314
	nique 245	8.7	<b>Evaluation of Separation Processes</b>
7.4	Regulation Technique 258		316
7.5	Process Computers 262	8.8	Literature 317
7.5.1	Tasks of Process Computers 264		
7.5.2	Requirements for Process		
	Computers 271		
7.5.3	Hardware 271		
7.5.4	Software 275		
7.5.5	Process Computers in	Part	III
	Biotechnology 276	$p_{roc}$	esses and Products
7.6	Literature 277	1100	esses and Froducis
8	Product Recovery in Biotechnology 279	9	Biotechnological Processes for the Manufacture of Foodstuffs
0.1	T = 1 = 200		and Fodders 325
8.1	Introduction 280	0.1	Later describer 226
8.2 8.2.1	Separation 280 Flocculation and Flotation 280	9.1 9.2	Introduction 326
8.2.1	Flocculation and Flotation 280 Filtration 281	9.2	Foodstuffs and Fodders of Plant Origin 326
8.2.3	Centrifugation 285	9.2.1	Origin 326 Silage 326
8.3	Disintegration 288	9.2.1	Fermented Vegetables 329
8.3.1	Disintegration of Animal and Plant	9.2.3	Asian Fermentation Products 333
0.5.1	Tissue 288	9.2.4	Raising Agents for Baked Products
8.3.2	Disintegration of Microorganisms	7.2.4	337
0.0.2	289	9.2.5	Fermentation of Semiluxury
8.4	Enrichment 292	71210	Consumer Goods 342
8.4.1	Concentration by Thermal	9.2.6	Cultivation of Edible Fungi 343
	Processes 292	9.3	Foodstuffs and Fodders of Animal
8.4.2	Extraction 293		Origin 346
8.4.3	Membrane Filtration 295	9.3.1	Milk and Dairy Products 346
8.4.4	Freeze-concentration 299	9.3.2	Meat and Sausage Products 371

9.4

9.4.1

9.4.2

9.5

Starter and Ripening Cultures 373

Definition 373

Literature 376

Manufacture 373

10	Fermentation Processes -	11.3	Products 440
	Ethanol, Wine, Beer 381	11.3.1	Organic Acids 440
		11.3.2	Amino Acids 449
10.1	Ethanol 382	11.3.3	Polysaccharides 449
10.1.1	General Observations 382	11.3.4	Vitamins and Provitamins 456
10.1.2	Importance of Alcohol 382	11.3.5	Alcohols and Solvents 459
10.1.3	Raw Material 382	11.3.6	Miscellaneous Products 464
10.1.4	Auxiliary Materials 383	11.4	Literature 468
10.1.5	Fermenting Organisms (Yeasts) 383		
10.1.6	Preparation of the Fermentation		
10.1.0	Substrate 384		
10.1.7	Formation of Ethanol 389	12	Enzymes 473
10.1.7	Recovery of Ethanol (Distillation)		•
10.1.0	395		
10.1.9	Utilization of Slops (Stillage) 397	12.1	Basic Concepts 474
	Potable Alcohol 398	12.2	Production of Enzymes 476
	Literature 401	12.2.1	Sources of Enzymes 476
10.2	Wine 404	12.2.2	Selection of Suitable Strains and
10.2.1	General Observations 404		Mutants of Microorganisms 467
10.2.2	Harvesting of the Grapes and	12.2.3	Nutrient Media 477
10.2.2	Pressing 407	12.2.4	Fermentation 478
10.2.3	Fermentation 411	12.3	Isolation of Enzymes 480
10.2.4	Wine Finishing 417	12.3.1	Disintegration of Biological
10.2.5	Improvement Processes 419		Material 480
10.2.6	Literature 424	12.3.2	Precipitation Processes 481
10.3	Beer 425	12.3.3	Separation of Solids 483
10.3.1	Definition of the Term 425	12.3.4	Purification 486
10.3.2	Raw Materials 425	12.3.5	Concentration 489
10.3.3	Preparation of the Malt 427	12.3.6	Desalting 490
10.3.4	Preparation of the Beer 429	12.3.7	Drying 491
10.3.5	Literature 435	12.3.8	Storage and Transport 491
10.5.5	Entertail 133	12.4	Immobilization of Enzymes 492
		12.5	Industrial Enzymes 493
		12.5.1	Proteases 493
11	Primary Metabolites 437	12.5.2	α-Amylases 499
		12.5.3	Glucoamylase 500
11.1	Introduction 438	12.5.4	Pullulanase 501
11.2	Technical Processes 438	12.5.5	Glucose Isomerase 501
11.2.1	Surface Processes on Solid	12.5.6	Pectinases 504
	Substrates 438	12.5.7	Cellulases 504
11.2.2	Surface Processes on Liquid	12.5.8	β-Galactosidase 504
	Substrates 438	12.5.9	Other Enzymes 504
11.2.3	Submerged Processes, Anaerobic	12.6	Therapeutic Use of Enzymes 506
	438	12.7	Enzymatic Analysis 507
11.2.4	Submerged Processes, Aerobic 439	12.8	Literature 509

13	Antibiotics and Other	14.7.5	1,2-Dehydrogenation 583
	Secondary Metabolites 515	14.7.6	Ester Saponification and Oxidation
	,		of Hydroxy Groups 584
13.1	Introduction 516	14.7.7	Reduction of Keto Groups 584
13.2	β-Lactams 528	14.7.8	Sterol Side-Chain Degradation 585
13.2.1	Penicillins 528	14.7.9	Other Types of Reactions in
13.2.2	Cephalosporins and		Microbiological Transformations of
	7-Methoxycephalosporins 530		Steroids 586
13.2.3	New Basic β-Lactam Skeletons 533	14.8	Prostaglandins 586
13.3	Aminoglycosides 537	14.8.1	Imitation of the Biogenesis of
13.4	Tetracyclines 541		Prostaglandins 587
13.5	Macrolide Antibiotics 543	14.8.2	Chemical Synthesis with Supporting
13.6	Anthracycline Antibiotics 546		Microbiological Reaction Steps 587
13.7	Ansamycins 548	14.8.3	Microbial Transformations of Native
13.8	Literature 552		or Artificial Prostaglandins 590
		14.9	Miscellaneous Products 590
	D1	14.10	Literature 594
14	Biotransformations 563		
	Investment of the		
14.1	Introduction 564	15	Production of Microbial
14.2	Methods 564	13	
14.2.1	General 564		Biomass 601
14.2.2	Transformation Techniques 565	15.1	D. C. 11: 1.D. 1 (02
14.3	Amino Acids 566	15.1	Definition and Review 602
14.3.1	Resolution of Racemates by	15.2	Raw Materials 604
1422	Enantioselective Hydrolysis 568	15.2.1	Basic Chemical Substances and
14.3.2	Formation of L-Amino Acids from	1522	Intermediates 604
1422	Synthetic Precursors 571	15.2.2	Complex Organic Compounds 606
14.3.3	Degradative Biotransformations	15.2.3	Sources of Nitrogen 607
14.4	572 Vitamins 574	15.2.4	Other Raw Materials 607
14.4	Carotenoids and Related	15.2.5	Energy Demand 608
14.3	Compounds 577	15.3	Microorganisms 608
14.6	Antibiotics 578	15.3.1	Methane-assimilating
14.6.1	Microbiological Transformations	15.3.2	Microorganisms 608 Methanol-assimilating
14.0.1	580	13.3.2	Microorganisms 610
14.6.2	Modified Biosynthesis of	15.3.3	Ethanol- and Acetate-assimilating
14.0.2	Antibiotics 580	13.3.3	Microorganisms 610
14.6.3	Mutasynthesis 581	15.3.4	Carbohydrate-assimilating
14.7	Steroids 581	13.3.4	Microorganisms 610
14.7.1	11-α-Hydroxylation 582	15.3.5	Carbon-dioxide-assimilating
14.7.1	11-β-Hydroxylation 582	10.5.5	Microorganisms 610
14.7.3	16-α-Hydroxylation 583	15.4	Processes and Apparatus 611
14.7.4	Hydroxylation of Other Positions	15.4.1	Preparation of the Raw Material
1-7-7-7	583	13.4.1	611

15.4.2	Fermentation 612	16.10	Biology of the Formation of
15.4.3	Processing 613		Methane 638
15.5	Process Examples 613	16.10.1	Hydrolytic and Acid-forming
15.5.1	Biomass from Methane 615		(Fermentative) Bacteria 639
15.5.2	Biomass from Methanol 615	16.10.2	Bacteria Forming Acetic Acid and
15.5.3	Biomass from Ethanol 616		Hydrogen (Acetogenic Bacteria)
15.5.4	Biomass from Normal Paraffins		639
	616	16.10.3	Methane-forming (Methanogenic)
15.5.5	Biomass from Carbohydrate-		Bacteria 641
	containing Raw Materials 616	16.11	Technical Processes 643
15.5.6	Biomass from Carbon Dioxide 617	16.11.1	Sludge Digestion 643
15.5.7	Biomass Products and Economic	16.11.2	Degradation of Wastewater Highly
	Aspects 618		Loaded with Organic Matter 645
15.6	Economic Aspects 620	16.12	Process Conditions 648
15.6.1	Variables Resulting from the	16.12.1	Composition of the Wastewater 649
	Process 620	16.12.2	Temperature 650
15.6.2	Product-specific Variables 621	16.12.3	pH 651
15.7	Literature 622		Biological Purification of Waste Air
			and Degradation of Solid Wastes
			653
16	Environmental Dietachnology	16.13	Processes for the Biological
16	Environmental Biotechnology	10.15	Purification of Waste Air 653
	623	16.14	Processes for the Biological
	Purification of Wastewater by		Degradation of Solid Wastes 653
	Aerobic Processes 624	16.15	Literature 657
16.1	Historical Development 624	23123	
16.2	Wastewater 624		
16.2.1	Communal Sewage 625		
16.2.2	Industrial Effluents 626	17	Microbial Leaching 661
16.2.3	Properties of the Substrate		8
	"Wastewater" 627	17.1	T-1-1-1-1-1-1-1-1-1-1-1-1-1-1-1-1-1-1-1
16.3	Aims and Limitations of the Aerobic	17.1	Introduction 662
	Biological Processing of Wastewater	17.2	Microorganisms 662
	Purification 627	17.2.1	Thiobacilli 662
16.4	Trickling Filter Process 628	17.2.2	Thermophilic Microorganisms 663
16.5	Activated Sludge Process 631	17.3	Reaction Mechanisms 663
16.6	Lagoon Process 635	17.3.1 17.3.2	Direct Bacterial Leaching 663
16.7	Sewage Treatment Processes as		Indirect Bacterial Leaching 664
	Special Forms of Biotechnology	17.4	Modification of the Bacterial
	636	17.4.1	Activity 665 Nutrients 665
16.8	Column Wastewater Reactors 636	17.4.1	
	Durification of Effluents by		pH and Eh 666
	Purification of Effluents by	17.4.3	Temperature 666 Chemistry and Mineralogy of the
16.0	Anaerobic Processes 638 General 638	17.4.4	Chemistry and Mineralogy of the Leaching Material 666
16.9	General 030		Leaching Material 666

17.4.5	Grain Size and Concentration of the Substrate 667	Appendix
17.4.6	Surface-active Agents and Organic	
	Extractants 667	
17.4.7	Heavy Metals 667	
17.4.8	Light 668	A
17.5	Microbial Leaching Processes 668	Appendix I
17.5.1	Laboratory Investigations 668	Journals, Periodicals, Reviews 700
17.5.2	Technical Leaching Processes 672	
17.6	Technical Applications 675	
17.6.1	Leaching of Copper Ores 675	Appendix II
17.6.2	Leaching of Uranium Ores 677	Biotechnological Abbreviations,
17.7	Future Aspects 678	Formulas, and Symbols 704
17.8	Literature 680	Tormulas, and Symbols 704
		A II.1 Fermentation Terms 704
10	E - CE	A II.2 Biotechnological Formulas 706
18	Economic Aspects of Fermenta-	A II.3 Biochemical Compounds and
	tion Processes 685	Abbreviations 706
		A II.4 Genetic Engineering Terms 707
18.1	Introduction 686	A II.5 Selection of Antibiotics
18.2	Main Factors of Profitability 687	(Names and Formulas) 708
18.2.1	Energy 688	A II.6 Technical Terms at the Fermenter
18.2.2	Fermentation Substrates 689	715
18.2.3	Working Materials 690	A II.7 Basic Physical Magnitudes 716
18.2.4	Environmental Protection 691	71 11.7 Busic Fifysical Wagineades 710
18.2.5	Capital Costs 691	
18.3	Examples of Products 691	Appendix III
18.3.1	Manufacturing Costs for	
	Penicillin G 691	Laws, Guidelines, and Instructions
18.3.2	Manufacturing Costs for Penicillin	717
	Amidase 693	
18.3.3	Manufacturing Costs of Citric Acid	
4 - 4	694	Appendix IV
18.3.4	Manufacturing Costs of Fuel	<b>Basic Information for Working in</b>
	Alcohol 694	Biotechnology 719
18.3.5	Manufacturing Costs of Bioprotein	Division of the second of the
	from Methanol 695	A IV.1 Selection of Culture Collections
18.4	Economic Data for Various	719
	Manufacturers and Product	A IV.2 Substrates for Fermentations 719
	Capacities of Bioproducts 695	A IV.3 Basic Operations of Fermentation
		and Recovery Techniques 724
		A IV.4 Flow Sheets of Typical
		Biotechnological Processes 735
		A IV.5 Types of Reactors 742

#### Appendix V Manufacturing Firms 743

A V.1 Some Manufacturers of Important Biotechnological Apparatus 743

A V.2 Some Manufacturers of Important Products 746 Appendix VI Products from Biotechnological Processes 750

Subject Index 753

#### Part I: Introduction