

高分子材料专业  
双语教材

# The Chemistry of Polymers (Second Edition)


# 聚合物化学

(第二版)

[英] 约翰·W. 尼科尔森 编著  
付中玉 译

***The Royal Society of Chemistry***

**John W. Nicholson**

 中国纺织出版社  
China Textile Press

高分子材料专业 双语教材

# **The Chemistry of Polymers** (Second Edition)

---

## **聚 合 物 化 学** (第二版)

[英] 约翰·W. 尼科尔森 编著

付中玉 译

中国纺织出版社

## 内 容 提 要

本书是配合高等院校高分子材料及相关专业实施双语教学而引进的英文原版经典教材,语言简洁、易懂,涵盖了聚合物化学领域的基本内容,注重实际应用,并反映了近年该领域的发展。

本书内容包括聚合物的结构和性质、聚合物的合成反应、聚合物的力学性能及一些重要话题,如聚合物的降解、聚合物的污染、多种聚合物的科技发展等。

本书可供高等院校高分子材料及相关专业师生使用,也可供高分子领域的科技人员参考。

原书名: The Chemistry of Polymers Second Edition

原著者: John W. Nicholson

本书中文简体注释版经 The Royal Society of Chemistry 授权,由中国纺织出版社独家出版发行。本书内容未经出版者书面许可,不得以任何方式或任何手段复制、转载或刊登。

著作权合同登记号: 图字: 01 - 2004 - 4441

### 图书在版编目(CIP)数据

聚合物化学/[英]约翰·W. 尼科尔森编著;付中玉译. —2版  
—北京:中国纺织出版社,2005.2

(高分子材料专业双语教材)

ISBN 7-5064-3282-X/TS·1937

I. 聚… II. ①尼… ②付… III. 高分子化学-双语教学-教材 IV. 063

中国版本图书馆 CIP 数据核字(2004)第 136596 号

---

策划编辑:冯 静 特约编辑:孙 玲 责任校对:陈 红  
责任设计:李 歆 责任印制:黄 放

---

中国纺织出版社出版发行

地址:北京东直门南大街6号 邮政编码 100027

电话:010-64160816 传真:010-64168226

http://www.c-textilep.com

E-mail: faxing@c-textilep.com

北京东远新宏印刷有限公司印刷 密云西康各庄装订厂装订

各地新华书店经销

2005年2月第1版第1次印刷

开本:787×1092 1/16 印张:13

字数:289千字 印数:1—3000 定价:35.00元

---

凡购本书,如有缺页、倒页、脱页,由本社市场营销部调换

# Preface

## 前 言

This book seeks to introduce readers to the chemistry of polymers. It is aimed primarily at new graduates who have not previously studied polymer chemistry as part of their degree course, but it ought to prove useful to others as well. I hope that final year students studying polymer chemistry and more experienced chemists in industry looking for concise information on the subject will find their needs met as well.

In preparing this book I have attempted to do two distinct things: (i) to provide a brief, readable introduction to the chemistry of polymers and (ii) to emphasise the applied aspects of the scientific knowledge presented. I believe that any introductory book ought to be written in a way that encourages its proposed audience actually to read it. Also as an applied scientist myself I want to emphasise the applications of polymer chemistry since I believe that these are worth covering in a book of this type.

No book, however brief, is the product of just one person. In my own case, I have been very conscious of the help I have received from many sources. These include authors of those books on polymer chemistry that I have drawn on in preparing this one, all of which are listed in the Bibliography.

I also want to give special thanks to my colleague Eleanor Wasson for her generous assistance in reading the entire manuscript and for her numerous helpful suggestions.

Lastly I thank my wife Suzette for her forbearance and support during my involvement with this project. Her good-natured tolerance of my frequent absence from family life has considerably assisted me in the completion of this book.

*John Nicholson*

## 出版前言

进入 21 世纪,各高校纷纷在提高教育素质、与国际接轨方面进行了积极的探索。其中“双语教学”成为推进素质教育的又一着陆点。教育部于 2001 年 8 月发布文件,针对本科教学工作提出 12 项措施,其中明确要求各高校在三年内开设 5% ~ 10% 的双语课程,并引进原版教材和提高师资水平。这使得高校双语教学势在必行。双语教学既是教育自身对课程设置的调整,也是社会发展对教育改革的必然要求。实施双语教学不仅可提高学生的英语水平,适应未来的发展,更重要的是提高我国综合国力和国际竞争力的需要。

通过问卷调查、座谈等方式,我们了解到双语教材的缺乏是高校实施双语教学的一大难点。作为科技出版社,我们拥有纺织、染化、服装、工美等专业人才,并和英美等国家的专业出版社、院校、协会保持着良好的合作,因此,我们希望利用自身专业优势,与高校合作出版双语教材,使之成为高校实施双语教学的先行兵。

经过广泛的调研、深入的讨论,我们在双语教材的内容、出版形式等方面形成了较完整的思路。目前,我社出版的双语教材按专业分为四个系列:纺织工程专业双语教材、轻化工程专业双语教材、高分子材料专业双语教材、服装专业双语教材。所选图书均为国外的经典教材,其内容与国内相关专业课程相近,便于学生在掌握专业基础知识的同时,开阔视野,提高语言应用能力。我们将力求出版形式多样化,既有原汁原味的影印本,又有中译本和中文注释版本。部分教材将配有多媒体光盘,更加丰富了教材的表现手段,有助于提高学生的英语听说能力。

可以说,这是我们在双语教材出版方面所进行的一次有意义的尝试,希望能对高校的双语教学的开展起到抛砖引玉之用,也希望读者对双语教材的出版提出建议、意见,以便我们在今后的工作中逐步改进、完善。

出版者

2004 年 11 月

# Preface to the Second Edition

## 第二版前言

The first edition of this book was, with one or two exceptions, gratifyingly well received by reviewers. It also sold well, thus confirming my belief that there is, indeed, place for an introductory book biased towards the more applied aspects of polymer science. It has been translated into Polish, suggesting that this need is international. Although it was not intended as a textbook for undergraduates, I have discovered that the first edition has been used for that purpose in certain universities, a point I have borne in mind in preparing the current edition.

In this second edition, I have stuck very much to the approach and level of the first edition, making changes only where absolutely necessary. In some cases this has been done to widen the coverage; in others it has been done to bring the text up to date. In making these changes, I have been helped by individuals who wrote to me after the publication of the first edition, with corrections or suggestions for additional material; I acknowledge my sincere gratitude for their help.

Despite this help, and the success of the first edition, I am sure that, even now, the book is not perfect. I am therefore still open to suggestions about how it could be improved. In the meantime, I take full responsibility for all the errors and infelicities that remain.

*John Nicholson, March 1997*

# Contents / 目 录

## Chapter 1

<b>Polymer Chemistry / 聚合物化学</b>	<b>1</b>
Basic Concepts / 基本概念	1
The History of the Concept of the Macromolecule / 高分子概念的历史	2
Classification of Polymers / 聚合物的分类	5
Structure and Properties of Polymers / 聚合物的结构和性质	6
Poly(ethylene) / 聚乙烯	7
Poly(propylene) / 聚丙烯	8
Poly(methyl methacrylate) / 聚甲基丙烯酸甲酯	9
Poly(styrene) / 聚苯乙烯	10
Poly(vinyl chloride), PVC / 聚氯乙烯	12
The Nylons / 尼龙	13
Epoxy Resins / 环氧树脂	15
Phenol-Formaldehyde Polymers / 酚醛聚合物	16
Amino Resins / 氨基树脂	17
Poly(tetrafluoroethylene), PTFE / 聚四氟乙烯	18
Polyurethanes / 聚氨酯	19
Poly(ether ether ketones) / 聚醚醚酮	20
Silicones / 硅氧烷	21
Naturally Occurring Polymers / 天然聚合物	21
Cellulose / 纤维素	22
Starch / 淀粉	22
Natural Rubber / 天然橡胶	23
Proteins / 蛋白质	24
Poly(3-hydroxybutyrate) / 聚 3-羟基丁酸酯	26

**Chapter 2**

<b>Polymerisation Reactions / 聚合反应</b>	<b>27</b>
Chain Polymerisation / 链式聚合	28
Initiation / 引发反应	28
Propagation / 增长反应	29
Termination / 终止反应	30
Other Reactions / 其他反应	31
Arrangement of Monomer Units / 单体单元的排列	32
Kinetics of Chain Polymerisation / 链式聚合反应的动力学	32
Autoacceleration / 自动加速(作用)	34
Practical Methods of Chain Polymerisation / 链式聚合反应的实施方法	35
Bulk Polymerisation / 本体聚合	36
Solution Polymerisation / 溶液聚合	37
Suspension Polymerisation / 悬浮聚合	37
Emulsion Polymerisation / 乳液聚合	38
The Loop Process / 环式工艺	39
Other Chain Polymerisation Mechanisms / 其他链式聚合机理	39
Step Polymerisation / 逐步聚合	42
Step Polymerisation with Polyfunctional Monomers / 多功能基团单体的逐步聚合	43
Copolymerisation / 共聚合反应	44

**Chapter 3**

<b>Polymer Structure / 聚合物结构</b>	<b>47</b>
Polymer Stereochemistry / 聚合物立体化学	47
Polymer Crystallinity / 聚合物结晶性	49
Orientation and Crystallisation / 取向和结晶	51
The Crystalline Melting Point / 晶体的熔点	52
Polyblends / 聚合物混合物	52
Thermal and Mechanical Properties / 热性能和力学性能	53
The Glass Transition Temperature, $T_g$ / 玻璃化转变温度 $T_g$	54
The Effect of Plasticisers / 增塑剂的影响	57
Methods of Determining Glass Transition Temperature / 测定玻璃化转变温度的方法	58
The Effect of Polymer Stereochemistry on $T_g$ / 聚合物立体化学对 $T_g$ 的影响	60



The Relationship between Crystalline Melting Point and $T_g$ / 结晶熔点和 $T_g$ 之间的关系	61
Other Thermal Transitions / 其他热转变	62
<b>Chapter 4</b>	
<b>Crosslinking / 交联</b>	63
Introduction / 引言	63
Phenol-Formaldehyde Resins / 酚醛树脂	66
Unsaturated Polyester Resins / 不饱和聚酯树脂	68
Polyurethanes / 聚氨酯	71
Epoxy Resins / 环氧树脂	73
<b>Chapter 5</b>	
<b>Polymer Solutions / 聚合物溶液</b>	77
Introduction / 引言	77
Dissolution of Polymers / 聚合物的溶解	77
Solubility Parameters / 溶解度参数	78
Simple Liquid Mixtures and Raoult's Law / 简单液态混合物和 Raoult 定律	80
Entropy of Mixing / 混合熵	81
Real Molecules in Dilute Solution / 稀溶液中的真分子	84
Shapes of Polymer Molecules in Solution / 聚合物分子在溶液中的形状	85
Reptation Model of Molecular Motion / 分子运动的蠕动模型	87
Water-soluble Polymers / 能溶于水的聚合物	88
Uses of High-viscosity Polymer Solutions / 高粘度聚合物溶液的用途	90
Polymer Melts / 聚合物熔体	92
<b>Chapter 6</b>	
<b>Methods of Determining Relative Molar Mass / 测定相对摩尔质量的方法</b>	94
Introduction / 引言	94
Molar Masses from Colligative Properties / 由依数性测定摩尔质量	96
Vapour Phase Osmometry / 气相渗透压测定法	97

Light Scattering / 光散射法	98
Experimental Determination / 实验测定	103
Viscosity Methods of Determining Relative Molar Mass / 测定相对摩尔质量的 粘度法	104
End Group Analysis / 端基分析法	106
Gel Permeation Chromatography / 凝胶渗透色谱法	107

## Chapter 7

<b>Mechanical Properties of Polymers / 聚合物的力学性能</b>	112
Introduction / 引言	112
Stress, Strain, and Young's Modulus / 应力、应变和杨氏模量	112
Brittle and Tough Fracture / 脆性和韧性断裂	113
Types of Strength / 强度的类型	116
The Influence of Surfaces / 表面的影响	118
Viscoelasticity / 粘弹性	121
Creep and Stress Relaxation / 蠕变和应力松弛	123
Cold Drawing / 冷拉伸	125
Dynamic Tests / 动态试验	126
Time/Temperature Relationship / 时间/温度关系	128
Rubberlike Elasticity / 橡胶弹性	130
Reinforced Polymers / 增强聚合物	133
Practical Measurements of Mechanical Properties / 力学性能的实际测定	136
Further Reading / 后续读物	137

## Chapter 8

<b>Polymer Degradation / 聚合物降解</b>	139
Introduction / 引言	139
Behaviour of Polymers in Fires / 聚合物的燃烧行为	139
The Behaviour of Individual Polymers / 单个聚合物的行为	141
Assessment of Combustion Behaviour / 燃烧行为的评价	141
Improvement of Stability of Polymers in Fires / 聚合物耐火性的改善	142

Weathering of Polymers / 聚合物的老化	144
Protection of Polymers from Photo-oxidation / 聚合物的防光氧化	146
Biological Degradation of Polymers / 聚合物的生物降解	149
Exploitation of Polymer Degradation / 聚合物降解的利用	150

### *Chapter 9*

<b>Special Topics in Polymer Chemistry / 关于聚合物化学的专题</b>	155
Introduction / 引言	155
Polymers in Medicine / 医用聚合物	155
Ionomers / 离子交联聚合物	158
Electronically Conducting Polymers / 导电聚合物	160
Interpenetrating Polymer Networks / 互穿聚合物网络	163
Inorganic Polymers / 无机聚合物	164
Polymer Liquid Crystals / 聚合物液晶	167
Polymers for Food Packaging / 用于食品包装的聚合物	169

### *Chapter 10*

<b>Polymers and the Environment / 聚合物与环境</b>	173
Introduction / 引言	173
Pollution by Polymers / 聚合物的污染	173
The Nature of the Problem / 问题的性质	176
Polymers and Energy / 聚合物和能量	177
Recycling of Polymers / 聚合物的再循环	178
Degradable Polymers / 可降解聚合物	180
The Future / 将来	181
<b>Bibliography / 参考文献</b>	183
<b>Subject Index / 主题词索引</b>	185

## Chapter 1

# Polymer Chemistry

# 聚合物化学

## BASIC CONCEPTS

## 基本概念

A polymer is a large molecule built up from numerous smaller molecules. These large molecules may be linear, slightly branched, or highly interconnected. In the latter case the structure develops into a large three-dimensional network.

线型的  
支化/交联  
三维网状

The small molecules used as the basic building blocks for these large molecules are known as monomers. For example the commercially important material poly(vinyl chloride) is made from the monomer vinyl chloride. The repeat unit in the polymer usually corresponds to the monomer from which the polymer was made. There are exceptions to this, though. Poly(vinyl alcohol) is formally considered to be made up of vinyl alcohol ( $\text{CH}_2\text{CHOH}$ ) repeat units but there is, in fact, no such monomer as vinyl alcohol. The appropriate molecular unit exists in the alternative tautomeric form, ethanal  $\text{CH}_3\text{CHO}$ . To make this polymer, it is necessary first to prepare poly(vinyl ethanoate) from the monomer vinyl ethanoate, and then to hydrolyse the product to yield the polymeric alcohol.

单体  
聚氯乙烯  
重复单元  
聚乙烯醇

The size of a polymer molecule may be defined either by its mass (see Chapter 6) or by the number of repeat units in the molecule. This latter indicator of size is called the degree of polymerisation, DP. The relative molar mass of the polymer is thus the product of the relative molar mass of the repeat unit and the DP.

互变(异构)的/乙醛  
聚乙酸乙烯酯  
水解  
乙醇

There is no clear cut boundary between polymer chemistry and the rest of chemistry. As a very rough guide, molecules of relative molar mass of at least 1000 or a DP of at least 100 are considered to fall into the domain of polymer chemistry.

The vast majority of polymers in commercial use are organic in

聚合度  
相对摩尔质量

有机的

共价的 nature, that is they are based on covalent compounds of carbon.  
 硅氧烷 This is also true of the silicones which, though based on silicon-  
 主链 oxygen backbones, also generally contain significant proportions  
 烃 of hydrocarbon groups. The other elements involved in polymer  
 氯 chemistry most commonly include hydrogen, oxygen, chlorine,  
 氟/磷/硫 fluorine, phosphorus, and sulfur, i.e. those elements which are  
 极性 able to form covalent bonds, albeit of some polarity, with carbon.

As is characteristic of covalent compounds, in addition to  
 化合价 primary valence forces, polymer molecules are also subject to  
 偶极 various secondary intermolecular forces. These include dipole  
 色散力 forces between oppositely charged ends of polar bonds and  
 氢键 dispersion forces which arise due to perturbations of the electron  
 负电性的 clouds about individual atoms within the polymer molecule.  
 蛋白质 Hydrogen bonding, which arises from the particularly intense  
 取向 dipoles associated with hydrogen atoms attached to electronega-  
 生物化学的 tive elements such as oxygen or nitrogen, is important in certain  
 polymers, notably proteins. Hydrogen bonds have the effect of  
 fixing the molecule in a particular orientation. These fixed  
 structures are essential for the specific functions that proteins  
 have in the biochemical processes of life.

## 高分子概念的历史

## THE HISTORY OF THE CONCEPT OF THE MACROMOLECULE

Modern books about polymer chemistry explain that the word  
 polymer is derived from the Greek words 'poly' meaning many  
 and 'meros' meaning part. They often then infer that it follows  
 that this term applies to giant molecules built up of large  
 numbers of interconnected monomer units. In fact this is mis-  
 leading since historically the word polymer was coined for other  
 reasons. The concept of polymerism was originally applied to the  
 situation in which molecules had identical empirical formulae but  
 very different chemical and physical properties. For example,  
 苯 benzene ( $C_6H_6$ ; empirical formula  $CH$ ) was considered to be a  
 乙炔 polymer of acetylene ( $C_2H_2$ ; empirical formula also  $CH$ ). Thus  
 the word 'polymer' is to be found in textbooks of organic  
 chemistry published up to about 1920 but not with its modern  
 meaning.

The situation is confused, however, by the case of certain  
 苯乙烯 chemicals. Styrene, for example, was known from the mid-nine-  
 teenth century as a clear organic liquid of characteristic pungent

odour. It was also known to convert itself under certain circumstances into a clear resinous solid that was almost odour-free, this resin then being called metastyrene. The formation of metastyrene from styrene was described as a polymerisation and metastyrene was held to be a polymer of styrene. However, these terms applied only in the sense that there was no change in empirical formula despite the very profound alteration in chemical and physical properties. There was no understanding of the cause of this change and certainly the chemists of the time had no idea of what had happened to the styrene that was remotely akin to the modern view of polymerisation.

树脂/介苯乙烯  
聚合

Understanding of the fundamental nature of those materials now called polymers had to wait until the 1920s, when Herman Staudinger coined the word 'macromolecule' and thus clarified thinking. There was no ambiguity about this new term – it meant 'large molecule', again from the Greek, and these days is used almost interchangeably with the word polymer. Strictly speaking, though, the words are not synonymous. There is no reason in principle for a macromolecule to be composed of repeating structural units; in practice, however, they usually are. Staudinger's concept of macromolecules was not at all well received at first. His wife once recalled that he had 'encountered opposition in all his lectures'. Typical of this opposition was that of one distinguished organic chemist who declared that it was as if zoologists 'were told that somewhere in Africa an elephant was found who was 1500 feet long and 300 feet high'.

大分子

重复结构单元

There were essentially three reasons for this opposition. Firstly, many macromolecular compounds in solution behave as colloids. Hence they were assumed to be identical with the then known inorganic colloids. This in turn implied that they were not macromolecular at all, but were actually composed of small molecules bound together by ill-defined secondary forces. Such thinking led the German chemist C. D. Harries to pursue the search for the 'rubber molecule' in the early years of the twentieth century. He used various mild degradations of natural rubber, which he believed would destroy the colloidal character of the material and yield its constituent molecules, which were assumed to be fairly small. He was, of course, unsuccessful.

胶体

无机的

橡胶  
降解

The second reason for opposition to Staudinger's hypothesis was that it meant the loss of the concept of a single formula for a single compound. Macromolecules had to be written in the form

$(\text{CH}_2\text{CHX})_n$ , where  $n$  was a large number. Moreover, no means were available, or indeed are available, for discretely separating molecules where  $n = 100$  from those where  $n = 101$ . Any such attempted fractionation always gives a distribution of values of  $n$  and, even if the mean value of a fraction is actually  $n = 100$ , there are significant numbers of molecules of  $n = 99$ ,  $n = 101$ , and so on. Now the concept of one compound, one formula, with one formula being capable of both physical (*i.e.* spatial) and chemical interpretation, had been developed slowly and at some cost, with many long, hard-fought battles. Organic chemists could not easily throw it out, particularly in view of the fact that it had been so conspicuously successful with much of the rest of organic chemistry.

聚合材料  
非晶性的  
胶  
萃取/结晶的  
The third reason for opposition lay in the nature of many of the polymeric materials then known. Not only were they apparently ill-characterised, but they were also frequently non-crystalline, existing as gums and resins. Just the sort of unpromising media, in fact, from which dextrous organic chemists had become used to extracting crystalline substances of well characterised physical and chemical properties. To accept such resins as inherently non-crystallisable and not capable of purification in the traditional sense of the word was too much for the self-esteem of many professional organic chemists.

胶质的  
Staudinger's original paper opposing the prevalent colloidal view of certain organic materials was published in 1920 and contained mainly negative evidence. Firstly, he showed that the organic substances retained their colloidal nature in all solvents in which they dissolve; by contrast, inorganic colloids lose their colloidal character when the solvent is changed. Secondly, contrary to what would have been expected, colloidal character was able to survive chemical modification of the original substance.

By about 1930 Staudinger and others had accumulated much evidence in favour of the macromolecular hypothesis. The final part in establishing the concept was carried out by Wallace Carothers of the Du Pont company in the USA. He began his work in 1929 and stated at the outset that the aim was to prepare polymers of definite structure through the use of established organic reactions. Though his personal life was tragic, Carothers was an excellent chemist who succeeded brilliantly in his aim. By the end of his work he had not only demonstrated the relationship between structure and properties for a number of polymers,

but he had invented materials of tremendous commercial importance, including neoprene rubber and the nylons.

氯丁橡胶/尼龙

## CLASSIFICATION OF POLYMERS

## 聚合物的分类

There are a number of methods of classifying polymers. One is to adopt the approach of using their response to thermal treatment and to divide them into thermoplastics and thermosets. Thermoplastics are polymers which melt when heated and resolidify when cooled, while thermosets are those which do not melt when heated but, at sufficiently high temperatures, decompose irreversibly. This system has the benefit that there is a useful chemical distinction between the two groups. Thermoplastics comprise essentially linear or lightly branched polymer molecules, while thermosets are substantially crosslinked materials, consisting of an extensive three-dimensional network of covalent chemical bonding.

热处理

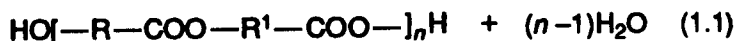
热塑性塑料/热固性塑料

分解

Another classification system, first suggested by Carothers in 1929, is based on the nature of the chemical reactions employed in the polymerisation. Here the two major groups are the condensation and the addition polymers. Condensation polymers are those prepared from monomers where reaction is accompanied by the loss of a small molecule, usually of water, for example polyesters which are formed by the condensation shown in Reaction 1.1.

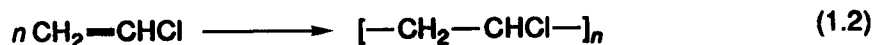
缩合/加成

聚酯



By contrast, addition polymers are those formed by the addition reaction of an unsaturated monomer, such as takes place in the polymerisation of vinyl chloride (Reaction 1.2).

不饱和的  
氯乙烯



This system was slightly modified by P. J. Flory, who placed the emphasis on the mechanisms of the polymerisation reactions. He reclassified polymerisations as step reactions or chain reactions corresponding approximately to condensation or addition in Carother's scheme, but not completely. A notable exception occurs with the synthesis of polyurethanes, which are formed by

机理

逐步反应/链式反应

聚氨酯



异氰酸酯/羟基  
动力学/消去

reaction of isocyanates with hydroxy compounds and follow 'step' kinetics, but without the elimination of a small molecule from the respective units (Reaction 1.3).



大分子

In the first of these, the kinetics are such that there is a gradual build up of high relative molar mass material as reaction proceeds, with the highest molar mass molecules not appearing until the very end of the reaction. On the other hand, chain reactions, which occur only at a relatively few activated sites within the reacting medium, occur with rapid build up of a few high relative molar mass molecules while the rest of the monomer remains unreacted. When formed, such macromolecules stay essentially unchanged while the rest of the monomer undergoes conversion. This means that large molecules appear very early in the polymerisation reaction, which is characterised by having both high relative molar mass and monomer molecules present for most of the duration of the reaction.

形态  
无支化的/交联的

Step reactions can give molecules having a variety of morphologies from the simple unbranched linear to the heavily crosslinked network. The final structure depends on the number of functional groups in the parent monomers – the greater the proportion with a functionality of greater than two, the more extensive will be the branching until, at sufficient degrees of branching, a highly crosslinked network emerges. Chain reactions, by contrast, give only linear or lightly branched polymers. Thus, in terms of the thermoplastic/thermoset classification, chain reactions give thermoplastics, while step reactions may give either thermoplastics or thermosets.

聚合物的结构和性质

## STRUCTURE AND PROPERTIES OF POLYMERS

Having established the basic principles of classification in polymer chemistry, we will now turn our attention to individual polymers and consider a little about their physical and chemical properties. Most of the examples which follow are of commercial importance, though it is their properties that are emphasised rather than the complete chemistry of their industrial manufacture. In terms of