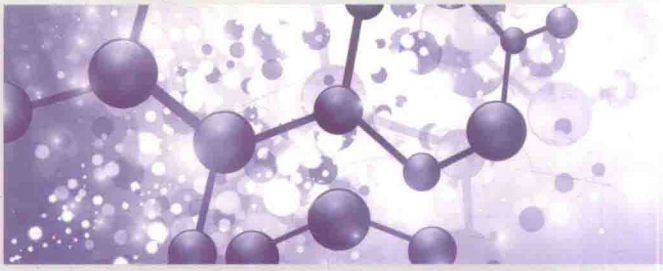
中国轻工业“十三五”规划立项教材
高分子材料与工程专业系列教材

聚合物科学与工程导论（第二版）

[英汉双语]

INTRODUCTION TO POLYMER SCIENCE AND ENGINEERING (SECOND EDITION)



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前　言

本教材是中国轻工业“十三五”规划立项教材，其前身是《高分子材料工程专业英语》，2010年改名为《聚合物科学与工程导论》，是应中国轻工业出版社委托，及国内二十几所轻工院校高分子材料与工程专业的要求而编写和修订的。自1999年该教材被列为本科生必修专业课程以来，该教材被国内20几所大学列为本科专业必修课程，经过近20年多届学生使用，效果较好。此次修订，除对第一版教材中各章内容，针对近年来的发展变化进行了修改和充实外，还增写了聚合物热分析单元。

本教材分为七个单元共45课，内容涉及聚合物发展史、聚合物科学基本概念、聚合物基础知识、聚合物合成、聚合物性能、聚合物热分析、聚合物材料和聚合物成型加工。

课文正文全部选用英文原版经典教材，使学生真正领会英文原版教材中专业知识的精髓。本教材既可作为高分子材料与工程专业必修的基础课，又可作为该领域专业课的双语教材或专业英语教学用书，也可作为从事高分子材料与工程研究领域的科技人员、教师及研究生提高业务及其专业英语水平的学习参考书。

本教材每课都附有练习题和阅读材料，便于学生对课文内容的理解，其阅读取材丰富，形式灵活，图文并茂、直观生动、深入浅出，简明易懂。每课除正文和阅读材料外，都标出了专业词汇的生词，并注有音标、常用短语和词组，并将课文的难点做了中文注释，可与中文内容对照学习。教材书后列出了总词汇表与术语的中英文对照表，便于查阅。

本教材由天津科技大学的揣成智、万同、褚立强、王彪编写。全书由主编揣成智、副主编万同统稿。

在本教材编写过程中，得到中国轻工业联合会、中国轻工业出版社、天津科技大学及兄弟院校有关领导和同仁的帮助与支持，谨此致谢。

由于水平所限，难免有不足和错漏之处，诚恳希望使用本书的读者批评指正。

编者

2019年3月

Content 目　　录

PART 1 INTRODUCTION
第一部分　概　　述

Lesson 1 Introduction to History of Polymer Science …… 1
聚合物科学史引言

History of Macromolecular Science …… 3
大分子科学史

Lesson 2 Basic Concepts of Polymer Science …… 7
聚合物科学基本概念

Basic Concepts of Polymers …… 9
聚合物基本概念

PART 2 FUNDAMENTALS OF POLYMER
第二部分　聚合物基础

Lesson 3 Types of Polymers …… 14
聚合物类型

Chemistry of Synthesis …… 17
合成化学

Lesson 4 Configurational States …… 19
构型状态

Conformational State …… 22
构象状态

Lesson 5 Structure of Synthesis …… 24
合成材料结构

Bonding in Polymers …… 26
聚合物键合

Lesson 6 Chain Conformation …… 29
链构象

Chains with Preferred Conformation …… 33
优先构象的链

Lesson 7 Polymer Morphology …… 36
聚合物形态

Amorphous Polymers …… 39
无定型聚合物

Lesson 8 Molar Mass …… 42
摩尔质量

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Characterization of Polymer Molecular Weight …… 44
聚合物相对分子量特征
Lesson 9 Polymer Solubility and Solutions …… 47
聚合物溶液和溶解性
The Thermodynamic Basis of Polymer Solubility and Solubility Parameter …… 50
聚合物溶解热力学基础和溶解度参数
Lesson 10 Transitions in Polymers …… 54
聚合物转变
Orientation and Drawing of Polymer …… 57
聚合物取向和拉伸

PART 3 POLYMER SYNTHESIS
第三部分 聚合物合成

Lesson 11 Step-Growth (Condensation) Polymerization …… 60
逐步增长（缩合）聚合
Step Reaction Polymerization …… 62
逐步反应聚合
Lesson 12 Free-Radical Addition (Chain-Growth) Polymerization …… 65
自由基加成（链增长）聚合
Chain Reaction Polymerization …… 67
链式反应聚合
Lesson 13 Emulsion Polymerization (1) …… 70
乳液聚合（1）
Emulsion Polymerization (2) …… 72
乳液聚合（2）
Lesson 14 Ionic Polymerization …… 75
离子聚合
Bulk Polymerization …… 77
本体聚合

PART 4 POLYMER PROPERTIES
第四部分 聚合物性能

Lesson 15 Rubber Elasticity …… 80
橡胶的弹性
Purely Viscous Flow …… 82
纯黏性流动
Lesson 16 Flow Curves of Polymer Fluid …… 85
聚合物流体的流动曲线
Time-Dependent Fluid Behavior …… 87
有时间依赖性流体的流动行为
Lesson 17 Polymer Melts and Solutions …… 89
聚合物熔融和溶解

Creep and Stress Relaxation of Polymer …… 90
聚合物蠕变和应力松弛
Lesson 18　Linear Viscoelasticity of Polymer …… 94
聚合物的线性黏弹性
Mechanical Behavior of Glassy, Amorphous Polymers Phenomenological Models …… 96
玻璃态，非晶态聚合物力学行为的唯象模型
Lesson 19　Time-Temperature Superposition of Polymer …… 102
聚合物的时－温等效
Temperature Dependence of Relaxation Time Spectrum …… 104
松弛时间谱的温度依赖性

PART 5　THERMAL ANALYSIS OF POLYMERS
第五部分 聚合物热分析

Lesson 20　Thermo-analytical Methods …… 108
热分析方法
Thermal Optical Analysis（TOA） …… 110
热光学分析（TOA）
Lesson 21　Differential Thermal Analysis and Calorimetry …… 111
差热分析和量热法
Thermogravimetry …… 114
热重分析法
Lesson 22　Dilatometry/Thermal Mechanical Analysis（TMA）and Dynamic Mechanical Thermal Analysis（DMTA） …… 116
膨胀/热力学分析（TMA）和动态力学热分析（DMTA）
Dielectric Thermal Analysis（DETA） …… 117
电介质热分析（DETA）
Lesson 23　Thermal Behavior of Semicrystalline Polymers …… 120
半晶态聚合物的热行为
Thermal Behavior of Amorphous Polymers …… 124
非晶态聚合物的热行为
Lesson 24　Thermal Behavior of Liquid-Crystalline Polymers …… 127
液晶聚合物的热行为
Polymer Degradation …… 128
聚合物降解

PART 6　POLYMER MATERIALS
第六部分　聚合物材料

Lesson 25　Plastics …… 131
塑料
The Historical Development of Plastics Industry …… 133
塑料工业发展史

Lesson 26 Thermoplastic Materials and Polyethylene Resins …… 136
热塑性材料和聚乙烯树脂
Polypropylene Resins …… 138
聚丙烯树脂
Lesson 27 Vinyl Resins and Polyvinyl Chloride …… 142
乙烯基树脂和聚氯乙烯
Styrene Resins and Polystyrene …… 144
苯乙烯树脂和聚苯乙烯
Lesson 28 Styrene-Acrylonitrile (SAN) and Acrylonitrile-Butadiene-Styrene (ABS) …… 147
苯乙烯－丙烯腈（SAN）和丙烯腈－丁二烯－苯乙烯共聚物（ABS）
Polyurethane …… 149
聚氨酯
Lesson 29 Polycarbonate …… 151
聚碳酸酯
Nylon …… 153
尼龙
Lesson 30 Epoxy Resins …… 156
环氧树脂
Tetrafluoroethylene Resins …… 158
四氟乙烯树脂
Lesson 31 Thermosetting Materials and Phenol Formaldehyde Resins …… 160
热固性材料和酚醛树脂
Polyester …… 162
聚酯
Lesson 32 The Historical Development of Rubber …… 165
橡胶发展史
Synthetic Rubber …… 167
合成橡胶
Lesson 33 Rubber Materials …… 170
橡胶材料
Rubber Mix and Compound Design …… 172
橡胶混合和配混设计
Lesson 34 Synthetic Fibers (1) …… 175
合成纤维（1）
Synthetic Fibers (2) …… 177
合成纤维（2）
Lesson 35 Adhesives …… 181
黏合剂
Five Organic Adhesives …… 183
五种有机黏合剂

PART 7　POLYMER MOLDING AND PROCESSING
第七部分　聚合物成型加工

Lesson 36　Plastics Molding and Processing …… 187
塑料成型加工
Rubber Product Manufacturing Systems …… 189
橡胶制品制造体系
Lesson 37　Injection Molding …… 193
注塑模塑
Injection Molding Machines and Molds …… 195
注塑机和模具
Lesson 38　Extrusion …… 198
挤出
Extrusion and Flat Sheet Extrusion …… 201
挤出和片材挤出
Lesson 39　Blow Molding …… 204
吹塑模塑
Blown Film, Flat and Wire Coating Extrusion …… 207
吹膜，平片和线材包覆挤出
Lesson 40　Calendering …… 211
压延
Laminating Molding …… 213
层压模塑
Lesson 41　Plastic Foam Molding …… 216
泡沫塑料模塑
Casting Molding …… 218
铸塑
Lesson 42　Thermoforming …… 221
热成型
Material Compounding of Polymer …… 225
聚合物的材料配制
Lesson 43　Rubber Mixing …… 227
橡胶的混炼
The Mechanisms of Rubber Mixing …… 228
橡胶的混炼机理
Lesson 44　Rubber Extrusion and Continuous Mixing …… 232
橡胶的挤出和连续混炼
Rubber Calendering and Vulcanization …… 234
橡胶压延和硫化
Lesson 45　Fiber Spinning of Polymer …… 236
聚合物纺丝

Principles of the Melt-Spinning of Polymer …… 239
聚合物熔融纺丝原理
Glossary …… 242
总词汇表
Phrases and Expressions …… 258
常用词和习惯用语索引
Primary References …… 267
主要参考文献

PART 1 INTRODUCTION

Lesson 1 Introduction to History of Polymer Science

Since the Second World War, polymeric materials have been the fastest-growing segments of the world chemical industry. It has been estimated that more than a third of the chemical research money is spent on polymers, with a correspondingly large proportion of technical personnel working in the area.

A modern automobile contains over 150 kg of plastics, and this does not include paints, the rubber in tires, or the fibers in tires and upholstery. New aircraft incorporate increasing amounts of polymers and polymer-based composites. With the need to save fuel and therefore weight, polymers will continue to replace traditional materials in the automotive and aircraft industries. Similarly, the applications of polymers in the building construction industry (piping, resilient flooring, siding, thermal and electrical insulation, paints, decorative laminates) are already impressive, and will become even more so in the future. A trip through a supermarket will quickly convince anyone of the importance of polymers in the packaging industry (bottles, films, trays). Many other examples could be cited, but to make a long story short, the use of polymers now outstrips that of metals on a mass basis.

People have objected to synthetic polymers because they are not "natural." Well, botulism is natural, but it's not particularly desirable. Seriously, if all the polyester and nylon fibers in use today were to be replaced by cotton and wool, their closest natural counterparts, calculations show that there wouldn't be enough arable land left to feed the populace[①] and we'd be overrun by sheep. The fact is there simply are no practical natural substitutes for many of the synthetic polymers used in modern society.

Since nearly all modern polymers have their origins in petroleum, it has been argued that this increased reliance on polymers constitutes an unnecessary drain on energy resources. However, the raw materials for polymers account for less than two percent of total petroleum and natural gas consumption, so even the total elimination of synthetic polymers would not contribute significantly to the conservation of hydrocarbon resources. Furthermore, when total energy costs (raw materials plus energy to manufacture and ship) are compared, the polymeric item often comes out well ahead of its traditional counterpart, e. g. , glass vs. plastic beverage bottles. In addition, the manufacturing processes used to produce polymers often generate considerably less environ-

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mental pollution than the processes used to produce the traditional counterparts, e. g. , polyethylene film vs. kraft paper for packaging.

Ironically, one of the most valuable properties of polymers, their chemical inertness, causes problems because polymers do not normally degrade in the environment. As a result, they contribute increasingly to litter and the consumption of scarce landfill space②. Progress is being made toward the solution of these problems. Environmentally degradable polymers are being developed, although this is basically a wasteful approach and we're not yet sure of the impact of the degradation products. Burning polymer waste for its fuel value makes more sense, because the polymers retain essentially the same heating value as the raw hydrocarbons from which they were made. Still, the polymers must be collected and this approach wastes the value added in manufacturing the polymers.

The ultimate solution is recycling. If waste polymers are to be recycled, they must first be collected. Unfortunately, there are literally dozens (maybe hundreds) of different polymers in the waste mix, and mixed polymers have mechanical properties about like cheddar cheese. Thus, for anything but the least-demanding applications (e. g. , parking bumpers, flower pots), the waste mix must be separated prior to recycling. To this end, automobile manufacturers are attempting to standardize on a few well-characterized plastics that can be recovered and re-used when the car is scrapped. Many objects made of the large-volume commodity plastics now have molded-in identifying marks, allowing hand sorting of the different materials.

Processes have been developed to separate the mixed plastics in the waste. The simplest of these is a sink-float scheme which takes advantage of density differences among the various plastics. Unfortunately, many plastic items are foamed, plated, or filled (mixed with nonpolymer components), which complicates density-based separations. Other separation processes are based on solubility differences between various polymers. An intermediate approach chemically degrades the waste polymer to the starting materials from which new polymer can be made.

1. New words

paint [peint] *n.* 颜料，油漆
rubber ['rʌbə] *n.* 橡胶
upholstery [ʌp'həulstəri] *n.* 室内装饰品
aircraft ['ɛəkra:ft] *n.* 航空器
siding ['saidiŋ] *n.* 板壁
polyester [ˌpɔli'estə] *n.* 聚酯
nylon ['nailən] *n.* 尼龙
botulism ['bɔtjulizəm] *n.* 肉毒中毒（食物中毒的一种）
counterpart ['kauntəpa:t] *n.* 对应物
arable ['ærəbl] *adj.* 可耕的，可开垦的
overrun [ˌəuvə'rʌn] *n.* 超出限度；*vt.* & *vi.* 泛滥
petroleum [pi'trəuliəm] *n.* 石油
hydrocarbon ['haidrəu'ka:bən] *n.* 烃，碳氢化合物
beverage ['bevəridʒ] *n.* 饮料
polyethylene [ˌpɔli'eθili:n] *n.* 聚乙烯

degrade[di'greid] *vt.* & *vi.* (使)降解,(使)退化
scarce[skɛəs] *adj.* 缺乏的,不足的
landfill['lændfil] *n.* 垃圾,垃圾掩埋法
bumper['bʌmpə] *n.* 缓冲器
component[kəm'pəunənt] *adj.* 组成的,合成的,成分的,分量的
cheddar['tʃedə] *n.* 干酪的一种

2. Phrases and expressions

polymer-based composites 聚合物基复合材料
resilient floor 弹性地板
electrical insulation 电绝缘
decorative laminates 装饰层压板
packaging industry 包装工业
energy resource 能源
raw material 原材料
account for 占,说明
kraft paper 牛皮纸

3. Notes to the text

①People have objected to synthetic polymers because they're not "natural." Well, botulism is natural, but it's not particularly desirable. Seriously, if all the polyester and nylon fibers in use today were to be replaced by cotton and wool, their closest natural counterparts, calculations show that there wouldn't be enough arable land left to feed the populace, …… 人们反感合成聚合物是因为合成聚合物不是"天然产物"。然而,食物中毒也是一种自然现象,但它却不是人们所需要的。严格说来,如果现今使用的聚酯和尼龙纤维都由棉花和羊毛这些自然界中最相近的纤维来替代,则有计算表明留给人类可耕种的土地将满足不了人们的粮食需要了。

②As a result, they contribute increasingly to litter and the consumption of scarce landfill space. 结果,垃圾日益增加,垃圾场日渐减少。

4. Exercises

(1) Consider the room you're in.

a. Identify the items in it that are made of polymers.

b. What would you make those items of if there were no polymers?

c. Why do you suppose polymers were chosen over competing materials (if any) for each particular application?

(2) Repeat Problem 1 for your automobile. Don't forget to look under the hood.

(3) You wish to develop a polymer to replace glass in widow glazing. What properties must a polymer have for that application?

Reading Material

History of Macromolecular Science

Natural polymers have been utilized throughout the ages. Since his beginning man

has been dependent upon animal and vegetable matter for sustenance, shelter, warmth, and other requirements and desires. Natural resins and gums have been used for thousands of years. Asphalt was utilized in pre-Biblical times; amber was known to the ancient Greeks; and gum mastic was used by the Romans.

In the search by the early organic chemists for pure compounds in high yields, many polymeric substances were discovered and as quickly discarded as oils, tars, or undistillable residues. A few of these materials, however, attracted interest. Poly(ethylene glycol) was prepared about 1860; the individual polymers with degree of polymerization up to 6 were isolated and their structures correctly assigned. The concept of extending the structure to very high molecular weights by continued condensation was understood.

Other condensation polymers were prepared in succeeding decades. As the molecular aggregation theories gained in popularity, structures involving small rings held together by secondary bond forces were often assigned to these products[①].

Some vinyl polymers were also discovered. Styrene was polymerized as early as 1839, isoprene in 1879, and methacrylic acid in 1880. Again cyclic structures held together by "partial valences" were assigned.

Acceptance of the macromolecular hypothesis came about in the 1920's, largely because of the efforts of Staudinger, who received the Nobel Prize in 1953 for his championship of this viewpoint[②]. In 1920 he proposed long-chain formulas for polystyrene, rubber, and polyoxymethylene. His extensive investigations of the latter polymers left no doubt as to their long-chain nature. More careful molecular weight measurements substantiated Staudinger's conclusions, as did x-ray studies showing structures for cellulose and other polymers which were compatible with chain formulas. The outstanding series of investigations by Carothers beginning in 1929 supplied quantitative evidence substantiating the macromolecular viewpoint.

One deterrent to the acceptance of the macromolecular theory was the problem of the ends of the long-chain molecules. Since the degree of polymerization of a typical polymer is several hundred, chemical methods for detecting end groups were at first not successful. Staudinger suggested that no end groups were needed to saturate terminal valences of the long chains; they were considered to be unreactive because of the size of the molecules. Large ring structures were also hypothesized; and this concept was popular for many years. Not until Flory elucidated the mechanism for chain-reaction polymerization did it become clear that the ends of long-chain molecules consist of normal, satisfied valence structures[③]. The presence and nature of end groups have since been investigated in detail by chemical methods.

Staudinger was among the first to recognize the large size of polymer molecules, and to utilize the dependence on molecular weight of a physical property, such as dilute

solution viscosity, for determining polymer molecular weights. He also understood clearly that synthetic polymers are polydisperse. A few years later, Lansing and Kraemer distinguished unmistakably among the various average molecular weights obtainable experimentally.

Staudinger's name is also associated with the first studies of the configuration of polymer chain atoms. He showed that the phenyl groups in polystyrene are attached to alternate chain carbon atoms. This regular head-to-tail configuration has since been established for most vinyl polymers. The mechanism for producing branches in normally linear vinyl polymers was introduced by Flory but such branches were not adequately identified and characterized for another decade. Natta first recognized the presence of stereospecific regularity in vinyl polymers.

1. New words

gum[gʌm] *n.* 胶
asphalt['æsfælt] *n.* 沥青,柏油
amber['æmbə] *n.* 琥珀
tar[ta:] *n.* 焦油
vinyl['vainil] *n.* 乙烯基
styrene['staiəri:n] *n.* 苯乙烯
glycol['glaikəl] *n.* 乙二醇
isoprene[ai'səupri:] *n.* 异戊二烯
methacrylic[me'θəkrilik] *adj.* 甲基丙烯类的
polystyrene[ˌpɔli'staiəri:n] *n.* 聚苯乙烯
polyoxymethylene[ˌpɔliˌɔksi'meθili:n] *n.* 聚甲醛
cellulose['seljuləus] *n.* 纤维素
deterrent[di'terənt] *n.* 阻碍物
viscosity[vis'kɔsiti] *n.* 黏度
distillable[dis'tiləbl] *adj.* 可由蒸馏而得的
residuum[ri'zidjuəm] *n.* 剩余,残滓
polydisperse[ˌpɔlidis'pə:s] *adj.* 多分散性的
phenyl['fenil] *n.* 苯基
configuration[kənˌfigju'reiʃən] *n.* 构型
stereospecific[ˌstiəriəuspə'sifik] *adj.* 有规立构定向的
elucidate[i'lju:sideit] *vt.* 阐明

2. Phrases and expressions

ethylene glycol 乙二醇
degree of polymerization 聚合度
molecular weight 分子量
secondary bond 次合键,次价力键
methacrylic acid 甲基丙烯酸,丙烯酸
long-chain 长链
end group 端基
chain-reaction 链式反应
dilute solution viscosity 稀溶液黏度
head-to-tail configuration 头尾构型

3. Notes to the text

①As the molecular aggregation theories gained in popularity, structures involving small rings held together by secondary bond forces were often assigned to these products. 由于分子缔合理论当时很盛行,人们经常把这些产品的结构看成是由次合键力结合起来的小环。

②Acceptance of the macromolecular hypothesis came about in the 1920's, largely because of the efforts of Staudinger, who received the Nobel Prize in 1953 for his championship of this viewpoint. 主要由于 Staudinger 的努力,20 世纪 20 年代高分子假说才被人们接受。由于他对这个观点的大力支持和提倡,1953 年他被授予诺贝尔奖。

③Not until Flory elucidated the mechanism for chain-reaction polymerization did it become clear that the ends of long-chain molecules consist of normal, satisfied valence structures. 直到 Flory 澄清链式反应聚合机理以后,人们才弄清楚长链分子反应末端是正常的价键结构。

Lesson 2 Basic Concepts of Polymer Science

Almost half a century ago, Wolfgang Ostwald coined the phrase "the land of neglected dimensions" to describe the range of sizes between molecular and macroscopic within which occur most colloidal particles. The term "neglected dimensions" might have been applied equally well to the world of polymer molecules, the high-molecular-weight compounds so important to man and his modern technology. It was not until the third decade of this century that the science of high polymers began to emerge, and the major growth of the technology of these materials came even later. Yet today polymer dimensions are neglected no more, for industries associated with polymeric materials employ more than a third of all American chemists and chemical engineers.

The science of macromolecules is divided between biological and nonbiological materials. Each is of great importance. Biological polymers form the very foundation of life and intelligence, and provide much of the food on which man exists. This book, however, is concerned with the chemistry, physics, and technology of nonbiological polymers. These are primarily the synthetic materials used for plastics, fibers, and elastomers, but a few naturally occurring polymers, such as rubber, wool, and cellulose, are included. Today, these substances are truly indispensable to mankind, being essential to his clothing, shelter, transportation, and communication, as well as to the conveniences of modern living.

A polymer is a large molecule built up by the repetition of small, simple chemical units. In some cases the repetition is linear, much as a chain is built up from its links. In other cases the chains are branched or interconnected to form three-dimensional networks①. The repeat unit of the polymer is usually equivalent or nearly equivalent to the monomer, or starting material from which the polymer is formed. Thus the repeat unit of poly(vinyl chloride) is $-CH_2CHCl-$; its monomer is vinyl chloride, $CH_2=CHCl$.

The length of the polymer chain is specified by the number of repeat units in the chain. This is called the degree of polymerization. The molecular weight of the polymer is the product of the molecular weight of the repeat unit and the degree of polymerization②. Using poly(vinyl chloride) as an example, a polymer of degree of polymerization 1,000 has a molecular weight of $63 \times 1,000 = 63,000$. Most high polymers useful for plastics, rubbers, or fibers have molecular weights between 10,000 and 1,000,000.

Unlike many products whose structure and reactions were well known before their industrial application, some polymers were produced on an industrial scale long before their chemistry or physics was studied. Empiricism in recipes, processes, and control

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