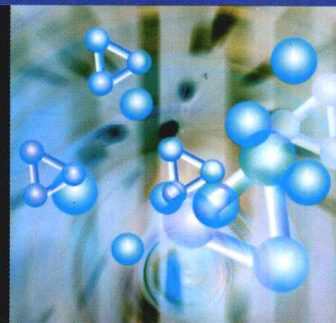[高分子材料与工程专业系列教材]

INTRODUCTION TO
POLYMER SCIENCE AND ENGINEERING

聚合物科学与工程导论

（英汉双语）

揣成智　主编　陈建生　主审

中国轻工业出版社

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前　言

为了贯彻教育部2001年(教高[2001]4号)《关于加强高等学校本科教学工作提高教学质量的若干意见》中关于"本科教育要创造条件使用英语等外语进行公共课和专业课教学"的文件精神,为了适应高等院校"高分子材料与工程"及相关专业教育的蓬勃发展和教育改革的不断深化,许多学校在高分子材料与工程专业教学中开始用双语教学替代原有的专业英语教学。这种双语教学不是简单的就英语而学英语,而是通过英语来学习专业知识。将专业英语学习与专业知识学习融合在一起的方法有利于为学生第一时间用英语阅读和吸收英语原版专业科技信息打下基础,有利于增强他们用英语进行专业交流的实际能力。然而,目前各学校的双语教学都处在摸索阶段,尚缺少能全面反映高分子材料与工程学科特点、内容适当、系统性强、可供学生和专业技术人员选用的高分子材料与工程双语教材,影响了本专业双语教学水平的提高及规范化。

本教材是为适应高等院校"高分子材料与工程"及相关专业实施双语教学而编写的,其特点为课文全部选用英文原版经典教材,课文语言标准、简洁、易懂,在内容上力求反映高分子材料与工程学科的特点和进展。同时,由于全书选用英文原版教材,本书将保留原文中的英制单位,请读者自行换算。

本教材选材力求在有限的篇幅内尽可能涵盖高分子材料与工程的学科领域。全书分为六个单元共36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、聚合物材料、聚合物加工工艺。涵盖了高分子化学、高分子物理、聚合物合成、高分子材料及其性能、聚合物加工等方面的内容,该教材反映了近年该领域的发展,使学生真正领会英文原版教材中专业知识的精髓。

本教材课文全部使用规范的高分子材料与工程专业的现代语言,概念清楚,定义准确,层次分明,语言流畅简洁,适教适学。课文阅读取材丰富,形式灵活,图文并茂、直观生动、深入浅出,简明易懂。

本教材每课除正文外,给出了课文中常用短语和词组、课文难点的中文注释,可与中文内容对照学习。主要专业词汇注有音标,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,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。

本教材既可作为高分子材料与工程专业基础课的双语教材或专业英语教学用书,也可作为从事高分子合成、高分子材料、成型加工、研制及应用工作的科技人员、教师及研究生提高业务及其专业英语应用水平的学习参考书。

本教材由天津科技大学揣成智主编,天津科技大学的李树老师及研究生李骏、王福强、程远、徐雪梅、赵楠和李春红等都参与了本教材的部分编写工作。全书由天津科技大学陈建生教授主审。

在本教材编写过程中,得到中国轻工业出版社、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。本教材编写还曾得到北京工商大学项爱民、河南工业大学张琳琪、天津科技大学万同等老师的建议和帮助,在此表示感谢。水平所限,文中错漏之处难免,敬请读者批评指正。

编者
2010 年 3 月

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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 environmental 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 space[②]. 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 reused 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
aircraft['eəkrɑːft] *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['kauntəpaːt] *n.* 对应物

arable['ærəbl] *a.* 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'kɑːbən] *n.* 烃，碳

氢化合物

beverage['bevəridʒ] *n.* 饮料

polyethylene[ˌpɔli'eθiliːn] *n.* 聚乙烯

degrade[di'greid] *vt. & vi.* （使）降解，（使）退化

scarce[skɛəs] *a.* 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] *a.* 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 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… 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类粮食的需要。

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 window glazing. What properties must the 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 six 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 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] a. 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] a. 可由蒸馏而得的
residuum[ri'zidjuəm] n. 剩余, 残滓
polydisperse[ˌpɔlidis'pə:s] a. 多分散性的
phenyl['fenil] n. 苯基
configuration[kənˌfigju'reiʃən] n. 构型
stereospecific[ˌstiəriəuspi'sifik] a. 有规立构的, 立体定向的
elucidate[i'lju:sideit] vt. 阐明

2. Phrases and expressions

ethylene glycol　乙二醇

degree of polymerization　聚合度

molecular weight　相对分子质量

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.　主要由于施陶丁格(Staudinger)的努力,二十世纪二十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年他获得了诺贝尔奖。

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 networks[1]. 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 polymerization[2]. 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 tests was usual.

Gradually the study of polymer properties began. Almost all were first called anomalous because they were so different from the properties of low-molecular-weight compounds. It was soon realized, however, that polymer molecules are many times larger than those of ordinary substances. The presumably anomalous properties of polymers were shown to be normal for such materials, as the consequences of their size were included in the theoretical treatments of their properties.

Primary chemical bonds along polymer chains are entirely satisfied. The only forces between molecules are secondary bond forces of attraction, which are weak relative to primary bond forces[3]. The high molecular weight of polymers allows these forces to build up enough to impart excellent strength, dimensional stability, and other mechanical properties to the substances[4].

1. New words

colloidal[kə'lɔidl] a. 胶状的, 胶质的
coin[kɔin] vt. 创造
elastomer[i'læstəmə] n. 弹性体
monomer['mɔnəmə] n. 单体
recipe['resipi] n. 配方, 处方

indispensable[ˌindis'pensəbl] a. 不可缺少的
empiricism[em'pirisizəm] n. 经验主义
anomalous[ə'nɔmələs] a. 反常的, 不规则的

2. Phrases and expression

build up 组成, 形成, 聚集
associate with 与……相关, 联合
three dimensional network 三维网状结构

repeat unit 重复单元
poly(vinyl chloride) 聚氯乙烯
primary bond 主价键
dimensional stability 尺寸稳定性

3. Notes to the text

①In 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 networks. 这些重复结构有的是线形的, 很像由一个一个的环构成的一条链子。有时这些链会分叉或相互连接成三维网状结构。

②The molecular weight of the polymer is the product of the molecular weight of the repeat unit and the degree of polymerization. 聚合物的相对分子质量是重复单元的相对分子质量与聚合度的乘积。