橡胶工程专业英语

Rubber Engineering Special English

杜爱华　主编

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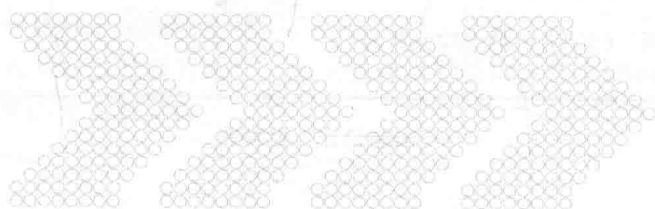
本书为橡胶工程专业英语教材，全书共分四部分，分别对聚合物的合成和结构；橡胶原材料配合体系如生胶、硫化体系、补强填充体系、防护体系等及配合原理；橡胶加工工艺，包括塑炼、混炼、压延、压出和硫化；橡胶循环利用等进行了系统的介绍。同时每章后面还附有相关词汇、短语的注释。

　　本书可作为高等院校具有橡胶工程特色的高分子材料与工程专业的专业英语教材，也可作为研究生的选修课教材，同时也可作为从事橡胶行业的工程技术人员的学习参考书。
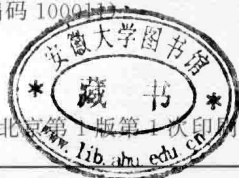
前言
Preface

在高等教育面向 21 世纪的改革中，尤其是具有工程特色的专业，对学生国际化视野、国际化交流与竞争意识的培养更为重要，其中专业英语水平则是衡量大学生素质能力的重要体现。橡胶行业的从业人员很多，学术和技术交流频繁，也迫切需要相关的专业外语书籍参考。目前关于高分子材料与工程、材料科学与工程的专业英语书籍很多，但是具有橡胶工程特色的高分子材料与工程专业英语还没有。在此背景下，编著者完成了本书的编写。本书可作为高等院校具有橡胶工程特色的高分子材料与工程专业的专业英语教材，也可作为研究生的选修课教材，同时也可作为从事橡胶行业的工程技术人员的学习参考书。

本教材分为四部分，共 13 章。第一部分为聚合物简介，包括聚合物的合成和结构；第二部分为橡胶原材料及科学，包括橡胶原材料配合体系如生胶、硫化体系、补强填充体系、防护体系等及配合原理；第三部分为橡胶加工工艺，包括塑炼、混炼、压延、压出和硫化；第四部分为橡胶循环利用。全书从弹性体材料合成、结构与性能、配合与加工、废旧橡胶制品的循环利用形成了一条完整的产业链，便于学生循序渐进地学习，既掌握专业外语，又了解行业情况。每章后面还附有词汇、短语的注释。

本教材编写分工如下：第 1 章、第 4 章～第 8 章由青岛科技大学杜爱华编写；第 2 章、第 3 章由青岛科技大学李琳编写；第 9 章～第 12 章由青岛科技大学赵菲编写；第 13 章由杜爱华和李琳共同编写。全书由杜爱华主编并负责统稿，由辛振祥教授负责主审。

本教材在编写过程中得到化学工业出版社的大力支持，同时得到青岛科技大学教务处的大力支持。青岛科技大学研究生王哲鹏、袁树建、王浩、丁明辉等为本书编写付出了辛勤劳动，在此一并表示深深的谢意。

由于本教材涉及内容较广，加上编者水平所限，书中如有不当和疏漏之处，恳请读者不吝指正，我们将不断完善。

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编者

2017 年 3 月

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Part I

Introduction to Polymers

Chapter 1 • Introduction

1.1 Introduction

Polymers are large molecules made up of simple repeating units. The name is derived from the Greek, poly means "many" and mer means "part". Macromolecule is a term synonymous with polymer. Polymers are synthesized from simple molecules called monomers (single part). A few representative monomers, together with the repeating units of the corresponding polymer, are given in the following reactions:

Ethylene $\qquad$ $CH_2=CH_2 \longrightarrow \{CH_2-CH_2\}$

Tetrafluorethylene $\qquad$ $CF_2=CF_2 \longrightarrow \{CF_2-CF_2\}$

Styrene

Methyl methacrylate $\qquad$ $CH_2=\overset{CH_3}{\underset{}{C}}-CO_2CH_3 \longrightarrow \left[CH_2\overset{CH_3}{\underset{CO_2CH_3}{C}}\right]$

1,3-Butadiene $\qquad$ $CH_2=CH-CH=CH_2 \longrightarrow \{CH_2-CH=CH-CH_2\}$

Ethylene oxide $\qquad$ $\overset{O}{CH_2-CH_2} \longrightarrow \{OCH_2CH_2\}$

Ethylene glycol $\qquad$ $HOCH_2CH_2OH \xrightarrow{(-H_2O)} \{OCH_2CH_2\}$

4-Hydroxymethyl benzoic acid $\qquad$ $HOCH_2 - \langle \text{benzene} \rangle - CO_2H \xrightarrow{(-H_2O)}$
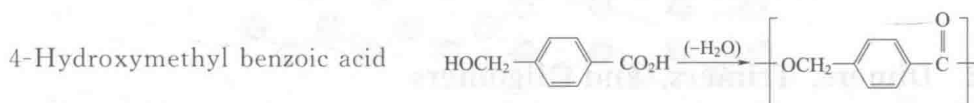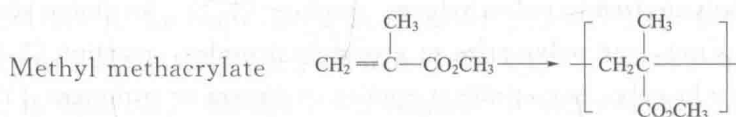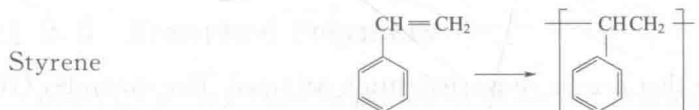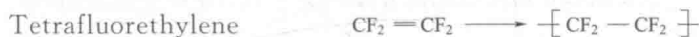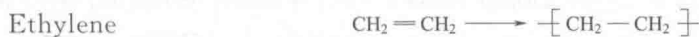
It should be noted that with the first six of the above eight examples the repeating units contain the same atoms as the corresponding monomers, whereas with the last two the repeating units contain fewer atoms because a by-product is formed in the polymerization process. The former types are commonly referred to as addition polymers, and the latter as condensation polymers. However, this terminology, while deeply ingrained in the language

of polymer chemistry, can lead to confusion, as is shown by the fact that the structures of the sixth and seventh examples are identical. Is $-\!\!\!\left[OCH_2\,CH_2\right]\!\!\!-$ an addition polymer or a condensation polymer? This ambiguity in defining polymer types will be considered latter. The first four examples involve ordinary addition to a double bond, while the fifth is an example of 1,4-addition of conjugated diene. Polymerization of the ethylene oxide involves a ring-opening reaction of a strained three-membered ring. Ethylene glycol gives the same product, a polyether, by dehydration, and 4-hydroxymethyl benzoic acid undergoes ordinary esterification to form ester. It should be noted that the fundamental difference between polymerization reaction of latter type and simple organic reactions is that di-or polyfunctional compounds are necessary for polymer formation, whereas monofunctional compounds can only form simple compounds. Thus, ethyl alcohol and benzoic acid react to form ethyl benzoate, whereas ethylene glycol and terephthalic acid give polyester.

$$\bigcirc\!\!-CO_2H + HOCH_2CH_3 \xrightarrow{(-H_2O)} \bigcirc\!\!-CO_2CH_2CH_3$$

$$\bigcirc\!\!-CO_2H + HOCH_2CH_2OH \xrightarrow{(-H_2O)} \left[\begin{matrix} O \\ \| \\ C \end{matrix}\!\!-\bigcirc\!\!-\begin{matrix} O \\ \| \\ COCH_2CH_2CO \end{matrix}\right]$$
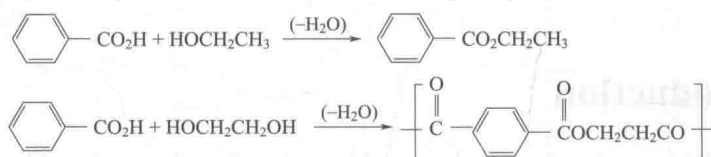
1.2 Definition- I

Many of the terms and definitions used in polymer chemistry are not encountered in conventional chemical textbook. Some of these definitions will seem fairly obvious, but others will need explanation.

1.2.1 Monomers

A monomer is any substance that can be converted into a polymer. For example, ethylene is a monomer that can be polymerized to polyethylene, reaction (1.1). An amino acid is a monomer which, by loss of water, can polymerize to give poly-peptides, reaction (1.2). The term monomer is used very loosely, sometimes it applies to dimers or trimmers if they themselves can undergo further polymerization.

$$CH_2 =\!\!= CH_2 \longrightarrow -CH_2-CH_2-CH_2-CH_2- \tag{1.1}$$

$$n H_2N-\begin{matrix} R \\ | \\ C \\ | \\ H \end{matrix}-\begin{matrix} O \\ \| \\ C \end{matrix}-OH \xrightarrow{(-H_2O)} \left[\begin{matrix} H \\ | \\ N \end{matrix}-\begin{matrix} R \\ | \\ C \\ | \\ H \end{matrix}-\begin{matrix} O \\ \| \\ C \end{matrix}\right]_n \tag{1.2}$$
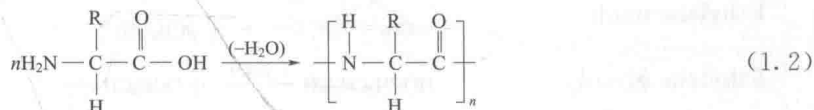
1.2.2 Dimers, Trimers, and Oligomers

The polymerization of a monomer often occurs in a sequential manner. In other words, two monomer molecules first react together to form a dimer. The dimer may then react with a third monomer to yield a trimer, and so on, can be linear or cyclic. low-molecule-weight polymerization products, for example, dimers, trimmers, tetramers, pentamers, etc. cyclic or linear is known as oligomers. Some care should be taken to avoid the use of the term "pol-

ymer" to describe materials that are really oligomers, because these two types of products have very different properties.

1.2.3 Polymers

The term polymer is used to describe high-molecular-weight substances. However, this is a very broad definition and in practice it is convenient to divide polymers into subcategories according to their molecular weight and structure. Although there is no general agreement on this point, in this book we will consider low polymers to have molecular weights below $10000 \sim 20000$ and high polymers to have molecular between 20000 and several million. Obviously, this is a rather arbitrary dividing line, and a better definition might be based on the number of repeating units in the structure. For example, since polymer properties become almost independent of molecular weight when more than $1000 \sim 2000$ repeating units are present, this point could also constitute a satisfactory dividing line between low and high polymers.

1.2.4 Linear Polymers

A linear polymer consists of a long chain of skeletal atoms to which are attached the substituent groups. Polyethylene is one of the simplest examples. Linear polymers are usually soluble in some solvent, in the solid state and at normal temperature they exist as elastomers, flexible materials, or glasslike thermoplastics. In addition to polyethylene, typical linear-type polymers include poly (vinyl chloride) or PVC, poly (methyl methacrylate) (also known as PMMA), polyacrylonitrile and nylon 66.

1.2.5 Branched Polymers

A branched polymer can be visualized as a linear polymer with branches of the same basic structure as the main chain. A branched polymer structure is illustrated in Figure 1.1. Branched polymers are often soluble in the same solvents as the corresponding linear polymer. In fact, they resemble linear polymers in many of their properties. However, they can sometimes be distinguished from linear polymers by their lower tendency to crystalize or by their different solution viscosity or light-scattering behavior. Heavily branched polymers may swell in certain liquids without dissolving completely.
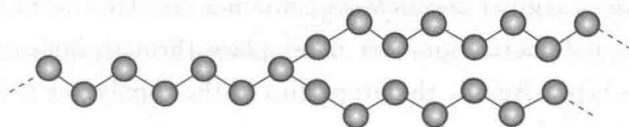

Figure 1.1　Branched polymer

1.2.6 Crosslinked Polymers

A crosslinked or network polymers is one in which chemical linkages exist between the chains, as illustrated in Figure 1.2. Such materials are usually swelled by "solvents", but

they do not dissolve. In fact, this insolubility can be used as cautious criterion of a crosslinked structure. Actually, the amount by which the polymer was swelled depends in the density of crosslinking: the more crosslink present, the smaller is the amount of swelling. If the degree of crosslinking is high enough, the polymer may be a rigid, unswellable solid. Light crosslinking of chains favor the formation of rubbery elastomeric properties.
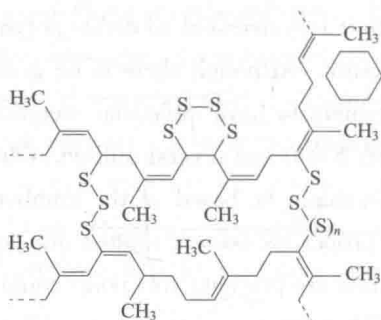
Figure 1.2   Crosslinked macromolecule

1.3   Definition-II

1.3.1   Copolymers

A copolymer is a polymer made from two or more different monomers. Many commercial synthetic polymers are copolymers. It should be noted that the sequence of monomer units along a copolymer chain can vary according to the method and mechanism of synthesis. Three different types of sequencing arrangements are commonly found.

(1) Random copolymers

In random copolymers, no definite sequence of monomer units exists. A copolymer of monomers A and B might be depicted by the arrangement shown in reaction (1.3). Random copolymers are often formed when olefin-type monomers copolymerized by free-radical-type processes. The properties of random copolymers are usually quite different from those of the related homopolymers.

$$-A-B-B-B-A-B-A-A-A-B-A- \tag{1.3}$$

(2) Regular copolymers

As the name implies, regular copolymers contain a regular alternating sequence of two monomer units. Olefin polymerization that takes place through ionic-type mechanisms can yield copolymer of this type. Again, the properties of the copolymer usually differ markedly from those of the two related homopolymers.

$$-A-B-A-B-A-B-A-B- \tag{1.4}$$

(3) Block copolymers

Block copolymers contain a block of one monomer connected to a block of another. Block copolymers usually formed by ionic polymerization process. Unlike other copolymers retain many of the physical characteristics of the homopolymers.

$$-A-A-A-A-B-B-B-B- \qquad (1.5)$$

1.3.2 Terpolymers

A terpolymer contains three different monomer units. There can be regular, random or blocks. For example, EPDM rubber is a typical terpolymer which is randomly copolymerized by ethylene, propylene and third monomer [usually diene, such as 1,4-hexadiene (1,4-HD), dicyclopentadiene (DCPD) and ethylidenenorbornene (ENB)].

1.3.3 Graft Copolymers

A graft copolymer is usually prepared by linking together two different polymers. For example, a homopolymer derived from monomer A may be induced to react with a homopolymer derived from monomer B to yield the graft copolymer shown in reaction (1.6). Graft polymers of this type can often be prepared by the gamma or X-irradiation of a mixture of the two homopolymers, or even by mechanical blending of the two homopolymers. Alternatively, a graft copolymer may be prepared by the polymerization of monomer B from initiation sites along the chain of polymer A. Graft copolymers often display properties that are related to those of the two homopolymers.
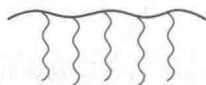
$$\qquad (1.6)$$

1.3.4 Thermoplastics

Basically, a thermoplastic is any material that becomes pliable or moldable above a specific temperature and solidifies upon cooling. However, the term is commonly used to describe a substance that passes through a definite sequence of property changes as its temperature is raised.

Most thermoplastics have a high molecular weight. The polymer chains associate through intermolecular forces, which weaken rapidly with increased temperature, yielding a viscous liquid. Thus, thermoplastics may be reshaped by heating and are typically used to produce parts by various polymer processing techniques such as injection molding, compression molding, calendering and extrusion.

Thermoplastics differ from thermosetting polymers, which form irreversible chemical bonds during the curing process. Thermosets do not melt, but decompose and do not reform upon cooling.

In Figure 1.3, the thermoplastic characteristics of an amorphous and a crystalline polymer are compared.

Both amorphous and crystalline thermoplastics are glass at low temperature, and both change from a glass to a rubbery elastomer or flexible plastic as the temperature is raised. This change from glass to elastomer usually takes place over a fairly narrow temperature, and this transition point is known as the glass transition temperature (T_g).
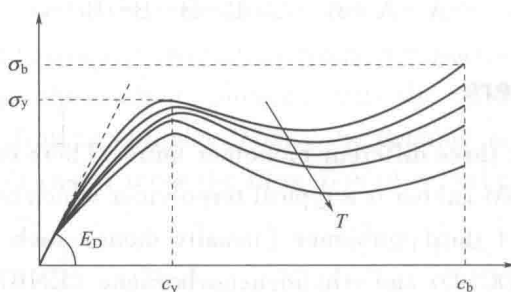
Figure 1.3   Stress-strain graph of a thermoplastic material

At temperature above T_g, amorphous polymers behave in a different manner from crystalline polymers. As the temperature of an amorphous polymer is raised, the rubbery elastomeric phase gradually gives way to a soft, extensible elastomeric phase, finally to a liquid. No sharp transition occurs from one phase to others, and only a gradually change in properties is perceptible.

Crystalline polymers, on the other hand, retain their rubber elastomeric or flexible properties above the glass transition, until the temperature reaches the melting temperature (T_m). At this point the material liquefies. At the same time, melting is accompanied by a loss of the optical birefringence and crystalline X-ray diffraction effects that are characteristic of the crystalline state.

Above its glass transition temperature and below its melting point, the physical properties of a thermoplastic change drastically without an associated phase change. Some thermoplastics do not fully crystallize below the glass transition temperature, retaining some or all of their amorphous characteristics. Amorphous and semi-amorphous plastics are used when high optical clarity is necessary, as light is scattered strongly by crystallites larger than its wavelength. Amorphous and semi-amorphous plastics are less resistant to chemical attack and environmental stress cracking because they lack a crystalline structure.

1.3.5   Elastomers

An elastomer is a polymer which is in the temperature range between its glass transition temperature and its liquefaction temperature. In practice elastomeric properties become more obvious if the polymer chains are lightly crosslinked. In particular, the liquefaction temperature may be raised by crosslinking, and the polymer may exhibit elastomeric properties over a wider temperature range.

Elastomeric properties appear when the backbone bonds can readily undergo torsional motions to permit uncoiling of the chains when the material is stretched (Figure 1.4). Crosslinking between the chains prevent the macromelocules from slipping past each other and thus prevent the material from becoming permanently elongated when held under tension. An important question connected with elasticity in this: why do the chains revert to the highly coiled state when the tension on elastomer is released? The answer lies in the fact that a highly coiled polymer system has a higher degree of disorder, therefore, a higher entropy than a

stretched, oriented sample. Thus, the elastic behavior is a direct consequence of the tendency of the system to assume spontaneously a state of maximum entropy. Since free energy, enthalpy, and entropy are related by the usual expression, $\Delta G = \Delta H - T\Delta S$, a stretched rubber band immediately held to the lips is warm, and the same material appears cold immediately after contraction.

Figure 1. 4 Rubbery elastomeric properties result from the stress induced
uncoiling and recoiling of polymer chains

1. 3. 6 Thermosetting Resin

The term thermosetting polymer refers to a range of systems which existinitially as liquids but which, on heating, undergo a reaction to form a solid, highly crosslinked matrix. A typical example is provided by the condensation of methylol melamine to give the hard, tough, crosslinked melamine resin. Partly polymerized systems which are still capable of liquid flow are called prepolymers. Prepolymers are often preferred as starting materials in technology. In practical terms, an uncrosslinked thermoplastic material can be reformed into a different shape by heating, but a thermosetting polymer can not.

1. 3. 7 Polymer Blends

When two or more polymers are mixed together mechanically, the product is known as a polymer blend. Many polymer blends display properties that are different from those of the individual polymers. Polymer blends can be of two types: (i) simple mixtures of the polymers, and (ii) genuine block or graft copolymers formed by the physical breaking of bonds, followed by bonding between the different polymeric fragments. The latter type or process can occur when two or more polymers are milled or masticated together. The mechanical shearing can result in the cleavage of bonds followed by cross-recombination.

● **Words and expressions**

macromolecule [ˌmækrəˈmɒləkjuːl]：高分子，大分子
synonymous with：与……同义
addition polymer：加成聚合物
condensation polymer：缩合聚合物
conjugated [ˈkɒndʒəgeɪtɪd]：共轭的
ethylene glycol [ˈeθəˌlin ˈglaɪkɔl]：乙二醇
polyether [ˈpɒliːˌiːθə]：聚醚，多醚
dehydration [ˌdihaɪˈdreʃən]：脱水

hydroxymethyl [haɪdrɒksɪˈmeθɪl]：羟甲基

esterification [eˌsterəfəˈkeɪʃən]：酯化作用

polyfunctional [pɒlɪˈfʌŋkʃənəl]：多官能的

ethyl benzoate [ˈɛθəl ˈbɛnzoˌet]：苯甲酸乙酯

terephthalic [ˈterefˈθælɪk]：对苯二酸

amino acid：氨基酸

polypeptide [ˌpɒlɪˈpepˌtaɪd]：多肽；缩多氨酸

oligomer [əˈlɪɡəmə]：低聚物，低聚体

subcategories [sʌbˈkætɪɡərɪz]：子分类；子范畴

skeletal atom：骨架原子

substituent group：取代基

methyl methacrylate：甲基丙烯酸甲酯

polyacrylonitrile [ˌpɒlɪˈækrəloʊˈnaɪtrɪl]：聚丙烯腈

light-scattering：光散射

olefin [ˈoʊləfɪn]：烯烃

hexadiene [ˈheksədɪrn]：己二烯

dicyclopentadiene [daɪsaɪkləpentəˈdiːn]：二环戊二烯

ethylidene norbornene：亚乙基降冰片烯

pliable [ˈplaɪəbəl]：柔韧的；柔顺的

calendering [kæˈlɪndərɪŋ]：压延

extrusion [ɪkˈstruʒən]：挤出

birefringence [ˌbaɪrɪˈfrɪndʒəns]：双折射

crystallite [ˈkrɪstəlaɪt]：微晶

crystalline [ˈkrɪstəlɪn, -ˌlaɪn, -ˌlin]：结晶的；结晶性

liquefaction [ˌlɪkwɪˈfækʃən]：液化；溶解

torsional [ˈtɔːʃənəl]：扭力的，扭转的

uncoiling [ʌnˈkɔɪlɪŋ]：伸开，展开

entropy [ˈɛntrəpi]：熵

enthalpy [enˈθælpɪ]：焓

contraction [kənˈtrækʃən]：收缩

methylol [miːθɪˈlɒl]：羟甲基

melamine [ˈmeləmiːn]：三聚氰胺

fragment [ˈfræɡmənt]：碎片，片段

masticated [ˈmæstɪˌkeɪtid]：粉碎，塑炼

hemolytic [hiːˈmɒlɪtɪk]：溶血的

cleavage [ˈklivɪdʒ]：分裂；裂开

Chapter 2 • Polymer Chemistry

2. 1 Rubber Polymerization

This chapter is intended to provide a general introduction to the industrial techniques used in rubber synthesis, by focusing on some relatively well known polymerizations that occur by chain-growth processes.

For rubber monomers, the polymerization process is classified by the way in which polymerization is initiated and thus the nature of the propagating chain, namely emulsion polymerization, solution polymerization and coordination polymerization etc.

2. 1. 1 Solution Polymerization

Polymerization method which monomer and initiator dissolving in appropriate solvents are called solution polymerization. It mainly includes the free radicals and ion solution polymerization.

There are many advantages for solution polymerization compared with bulk polymerization, such as low viscosity, easy mixing and heat transfer, high temperature control, less gel effect and no local overheating.

The solvent is crucial for this process. The choice of solvent is based on two principles because solvents have an effect on polymerization activity, the dissolution performance of polymer and gel effect.

This is perhaps the most well-known method of rubber polymerization. In the common synthetic rubbers, many kinds of rubber are synthesized in this way, such as polybutadiene rubber, polyisoprene rubber, styrene-butadiene rubber, polyacrylate rubber.

2. 1. 2 Emulsion Polymerization

Emulsion polymerization is frequently used for rubber synthesis. A variety of synthetic rubbers, such as styrene-butadiene, nitrile rubber, chloroprene rubber adopt emulsion polymerization method.

Mechanism and kinetics polymerization in aqueous emulsions, which has been widely developed technologically, represents a special case of free radical chain polymerization in a heterogeneous system. Most emulsion polymerization systems comprise a water-insoluble monomer in water with a surfactant and a free radical initiator. Although it might be thought that polymerization of water insoluble monomers in an emulsified state simply involves the direct transformation of a dispersion of monomer into a dispersion of polymer, this is not really the case, as evidenced by the following features of a true emulsion polymeri-

zation. The polymer emulsion (or latex) has a much smaller particle size than the emulsified monomer, by several orders of magnitude. The polymerization rate is much faster than that of the undiluted monomer, by one or two orders of magnitude. The molecular weight of the emulsion polymer is much greater than that obtained from bulk polymerization, by one or two orders of magnitude.

The mechanism of emulsion polymerization can best be understood by examining the components of this system, as depicted in Figure 2.1, for a typical "water-insoluble" monomer such as styrene (solubility=0.07g/L). Figure 2.1 shows the various loci in which monomer is found, and which compete with each other for the available free radicals. Thus, in the initial stages, the monomer is found in three loci: dissolved in aqueous solution, as emulsified droplets, and within the soap micelles. Both the dissolved monomer and the relatively large monomer droplets represent minor loci for reaction with the initiator radicals (except, of course, in the case of highly water-soluble monomers). The large number of soap micelles containing imbibed monomer, however, represents a statistically important locus for initiation of polymerization. It is thus not surprising that most of the polymer chains are generated within the monomer-swollen soap micelles. The large number (about $10^{15}/mL$) of very small polymer particles thus formed which are stabilized by adsorbing monolayers of soap until depleting the available molecularly dissolved soap, thus destroying the soap micelles at an early stage of the polymerization (about 10% conversion in the usual recipe). As all the available soap is distributed, and redistributed, over the surface of the growing particles, the amount of soap is the main factor controlling latex particle size. During the second stage of the emulsion polymerization, therefore, the loci for available monomer consist of the dissolved monomer, the free monomer droplets, and the monomer imbibed by the numerous polymer particles. As before, the first two of these loci make a minor contribution, whereas the polymer-monomer particles provide a major locus for reaction with the initiator radicals diffusing from the aqueous phase. The major portion of the polymerization reaction apparently occurs within this large number of latex particles which are isolated from each other by electrostatic repulsion and kept saturated with monomer diffusing from the monomer droplets. It is this aspect which leads to the unique characteristics of this system. Thus, once an initiator radical enters a polymer monomer particle and initiates a chain, the latter must continue to propagate with the available monomer until another radical enters the same particle. In this way, the rate of chain termination is actually controlled by the rate of entry of radicals into the particles, and this generally increases the lifetime of the growing chains, and hence the chain length. Furthermore, because the growing chains are all located in different particles, they are unable to terminate each other, leading to a higher concentration of growing chains and a hence faster rate.

A much faster rate and a much higher molecular weight are achieved by emulsion polymerization systems. It is obvious that the main difference lies in the fact that the emulsion system is capable of raising the steady-state concentration of growing chain radicals by two to three orders of magnitude. The situation described earlier, i. e. , where radicals entering in-