Properties of Polymers
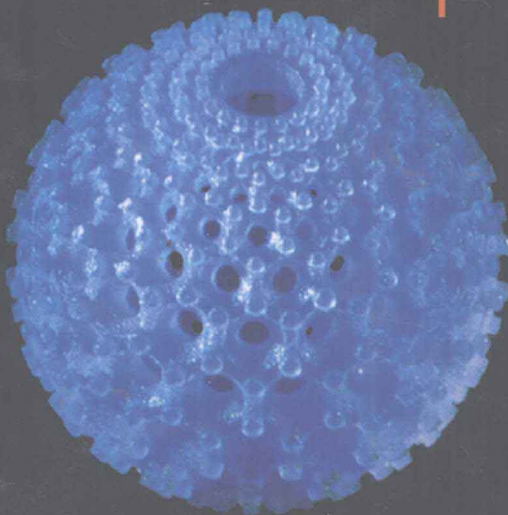
Their Correlation with Chemical Structure;
Their Numerical Estimation and Prediction from Additive Group Contributions

聚合物的性质

（原著第四版）

D.W. van Krevelen

K. te Nijenhuis

中 文 导 读

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　　一本科技图书有其或专或泛的读者群,也有其热销传播的鼎盛期。现在放在我们面前的这本书,初版于1972年。在此后的37年中,经第二版(1976年)、第三版(1990年),到现在的第四版,对19年前的第三版的内容加以修订、补充、更新与扩展。可见这本书选题之重要,及其学术价值与适用程度。

　　该书使从事聚合物科学与工程的学者与工程师,能对研究、生产的聚合物材料得到本征性质基本数据,再从聚合物化学结构与各类性质的关联上,基于化学基团可加和性原理,利用半经验或经验方法,估算出聚合物的一些性质、性能值。而且,它使需要认识与使用聚合物材料(通常人们称其为高分子材料)的其他学科的专业人士,能用便捷的方式、在较短的时间内得到他们所需的数据,并由此获知进一步查阅的途径。

1. 书名与内涵

　　本书书名为《PROPERTIES OF POLYMERS》。其中,英文名词"POLYMER"的汉译名为"聚合物"。其定义为"A substance composed of macromolecules"[1],汉译为"由高分子组成的物质"。由此上溯到英文名词"macromolecule",汉译为"高分子(又称大分子)"。其严格定义为"A molecule of high relative molecular mass, the structure of which essentially comprises the multiple repetition of units derived, actually or conceptually, from molecules of low relative molecular mass"[1],是指"在结构上由许多个实际或概念上的低分子量分子作为重复单元组成的高分子量分子"[2]。本书的重点是大量高分子组成的物质所表现出的性质与性能。因此,书名中的这一关键词应该译为"聚合物"。

　　书名中的另一个关键词是"PROPERTIES"。其汉译可以是"性质"或"性能"。在汉语中,我们通常使用化学性质、物理性质等术语;而对材料在光、电、磁、力、声和环境等外场作用下的响应与行为,则表述为"性质"或"性能",视场合约定俗成。作者在第3章开头就讨论了书名所包含的概念,并将它们分为不同而又密不可分的三类,即材料的本征性质、加工性能与产品制件性能。从本书的内容看,其第2篇论及体积、量热、转变、溶解、表面与界面、稀溶液等,均属于高分子的物理性质;随后占全书三分之二以上篇幅的第3至第6篇中的绝大部分内容,都是论述聚合物在光、电、磁、力、声和环境等外场作用下的响应与行为,在加工过程与使用环境下的表现。显然,书名中的第二个关键词包含了性质与性能。因此,虽说本书译名定为《聚合物的性质》,但是它是论述聚合物结构与性能关系的专著,从聚合物的化学结构估算、预测产品的一系列性能。清楚本书书名的内涵,将大大有助于对本书的充分利用。

2. 结构与内容

本书的副标题是"它们与化学结构的关系；以及由基团的可加性贡献所做的数值估算与预测"。其主要目的在于两个方面：

（1）将已知聚合物的性质与它们的化学结构关联起来，即建立结构-性能关系；

（2）对处于固态、液态或溶解状态的聚合物的最重要性质，当无法查到它们的实测值时，提供估算或预测的方法。

本书的特点在于从聚合物的化学结构与物理性质，利用基团贡献的可加和性，通过半经验公式估算聚合物的性质。

全书由 7 篇、27 章和附录组成。第 1 篇第 1 章突出本书关于预测估算的目的，以及利用半经验公式的途径。第 2 章介绍聚合物的基本概念，包括它们的化学结构、分子量与分子量分布、相转变、形态、高分子液晶，直到多组分聚合物体系、弛豫现象。第 3 章介绍性质的类型，诸多物理量，以及可加性摩尔函数，为以后的估算打下基础。

第 2 篇各章论及聚合物的本征性质，包括体积性质、量热性质、转变温度、内聚性质与溶解度、界面能性质和特性黏数。这些本征性质成为随后估算聚合物各类性质、性能的基本参数。

第 3 篇论述聚合物在光、电、磁、力、声和环境等外场作用下的各种响应，表现出的各种性质、性能。这些构成了聚合物材料的使用价值与应用领域。

第 4 篇讨论聚合物的输运性质，包括聚合物熔体的流变性质、聚合物溶液的流变性质、热传导性质、小分子在聚合物中的渗透与扩散、聚合物的结晶等。这些性质与聚合物材料的加工成型密切相关。

在讨论聚合物稳定性与崩溃的第 5 篇，涉及了热化学性质、热分解、化学降解。这些性质决定了聚合物材料的使用极限。

在总结性的第 6 篇，首先回顾了聚合物的本征性质，接着讨论聚合物的加工性能，并用两章篇幅分别论述产品的力学行为与失效、环境行为与失效，最后以纺织品为例，全面分析决定制品最终使用性能的美学、穿着、洗涤保养各方面，以指标的柱状图示法展示对纤维聚合物、纤维与纱的综合评价。

第 7 篇包含 60 多页的各类数据表格，从最基本的国际单位制、换算因子、基本常数值，到溶剂的物理常数、聚合物的物理性质、高性能聚合物的相关数据，甚至聚合物的商品名与通用名，几乎应有尽有。在对聚合物性质、性能作估算时，要用到的数据都能从本书中查到。

3. 查阅方法

本书前有目录，各章节标题很清楚地分列出各类性质与性能，查阅相关内容非常方便。前面已经对本书的结构与内容作了介绍，这里就不再赘述。

本书的最后编有索引，包括符号索引、作者索引和主题索引。从索引查找也很方便。对于符号索引，可以从符号的大小写字母查到所代表的物理量，与其在本书中出现的各章。其排列顺序为，先是按英文字母表、后是按希腊字母表；先是小写、后是大写；下标也是按字母表顺序排序；其余类推。最后是无量纲数。作者索引中的斜体页码，表示作者名出现在该页的一般参考书目中。从主题索引可以找到一个概念、术语在本书中所出现的页码。

本书又一特点是,对于聚合物所涉及的诸多性质、性能,先用简洁的文字叙述它们的基本概念与分类等内容,辅以结构式、示意图,较多地使用框图、数据表格和各类公式,使得众多内容直观、清晰。作者精心编写、前后呼应,例如在第 790 页回顾本征性质时,列出了表格与公式在本书中的位置,便于交叉查阅。

4. 进一步阅读

本书在每一章的最后都列有参考书目,分为两大类:一般参考书和专题参考文献。各章还有因不同的需求而加列的其他参考书类,如第 1 章列出了一些百科全书。

对于一般参考书,有几章根据其不同内容,分类列出书目。这样使得读者在需要进一步查找参考书时,不用再花费多余的时间从一大堆书目中挑出直接与某一内容相关的书目。例如,第 2 章分别列出了有关高分子结构、分子量分布、相转变与形态、高分子液晶、多组分体系及弛豫现象的一般参考书目;第 10 章分别列出了一般阅读、光学总论、双折射、偏振光、光散射、红外光谱学的相关书目;第 11 章分别列出了电介质极化、静电化与导电性、非线性光学的相关书目;第 12 章专门列出了核磁共振谱学的参考书目。

列出的专题参考文献表明书中所用的数据均有可靠的出处,有兴趣的读者可以循此进一步查阅。

5. 中译本

本书的特色使得我国的高分子界在它一面世便加以关注,早在 1973 年便翻译出版了第一版(1972 年)的中译本。随后,仍然由许元泽、赵得禄、吴大诚翻译,科学出版社于 1981 年出版第二版(1976 年)的中译本。这次,科学出版社于第四版原著出版的当年(2009 年)即与 Elsevier 公司签约,在选译第四版序言、目录并加上中文导读后在中国大陆出版。

纯属偶然,科学出版社得到北京大学陈尔强教授的建议,邀请我为这本书撰写中文导读。这对于被高分子前辈钱人元先生推荐去荷兰做博士后研究、先后五次因学术交流访问荷兰、对独具特色的荷兰高分子研究所(DPI)略知一二的我而言,不失为又一次更深地理解荷兰高分子圈的机会。本书作者 Van Krevelen 教授在 87 岁高龄时,与 Elsevier 公司签订了修订第三版的合同。在他因病住院中,听到合作伙伴 K. te Nijenhuis 教授已经与 Elsevier 公司签了合同,为之一扫愁容、容光焕发。我想这是他信守承诺的体现、落实重任的宽慰。Van Krevelen 教授在 30 多年中不断地为这本书注入自己的心血,使之内容不断丰富、得以一版再版,这是他从事聚合物科学的一大贡献。我们可能不知道他一生发表了多少篇研究论文,然而我们知道他有这本很有特色、经久不衰的著作。这也是跳出 SCI 论文与影响因子等数字统计,在学术上的一种更高层次、更高境界的追求。

参考文献

［1］ International Union of Pure and Applied Chemistry, Macromolecular Division, Commission on Mac-romolecular Nomenclature, Glossary of Basic Terms in Polymer Science(IUPAC Recommendations 1996), Pure & Appl. Chem., Vol. 68, No. 12, pp. 2287-2311, 1996.

［2］ 全国科学技术名词审定委员会公布,《化学名词及其定义》,科学出版社,北京(即将出版)。

第四版序言

从本书的第三版出版至今已经十八年过去了。作为重要的参考资料来源,本书至今仍在全世界广泛使用。

2000年初,在"荷兰高分子圈"中有一种感觉,那就是需要《聚合物的性质》修订版。在这之前,Elsevier公司就曾建议Van Krevelen教授考虑筹备他那本书的修订版。然而,由于年事已高,Van Krevelen教授觉得他一个人无力为筹备新的版本作出所有努力。为此,他于2001年5月邀请我与其合作筹备第四版。我知道这将是一项工作量巨大的任务,在犹豫中接受了这一荣幸邀请。我们一起与Elsevier公司讨论,结果于2001年秋天签订了合同。Van Krevelen教授将用他丰富的知识与经验支持我。不幸的是,他没能做到。因为,他在那年的10月27日就辞世了。我永远不会忘记,我于10月4日与他儿子Laurens同到医院探望他时,当他听说我也签了Elsevier的合同时,他那张容光焕发的脸。从此,无论如何我不得不单独完成这一任务,并且这确实是一件长期寂寞的工作。但是,每每想到在他一筹莫展时那张容光焕发的脸,不仅对我着手工作是一种激励,而且在继续完成这一宏大任务时也一直是如此。

现在的第四版已经作了更新,并在需要之处作了扩展。然而,我没有改变此书的想法,即没有改变此书原有7篇、27章的总体框架。下面将介绍何处作了些许修改,何处内容大为扩展了。

第1篇概论:聚合物科学与工程概览。第1章,涉及聚合物性能的途径与目的,几乎没有改动。第2章讨论了聚合物的类型,扩展并更新了那些里程碑(附录1),增添了与聚合物有关的诺贝尔奖获得者名单,更新了商品聚合物的发展史(附录2)。第3章讨论性能的类型,只做了少许改动与补充。

第2篇聚合物的热物理性质。第4、第5章分别涉及体积性质与量热性质,只作了一些旁注性的扩展。第6章讨论转变温度,更多地关注了玻璃—橡胶态转变的热力学。此外,改变了计算重复单元中带有两个功能基团的聚合物的熔融温度的处理方法,使得计算所得与实验所得的熔融温度更符合。第7章讨论内聚性质与溶解性,将溶度参数与Flory-Huggins相互作用参数作比较。并进一步增加了溶度参数的温度依赖性和混合溶剂的溶度参数。第8章论及界面能性质,增加了表面能方程中的修正项,以及借助Lifschitz-Van der Waals相互作用计算表面能贡献的更为精细的途径。第9章论及构象各方面与构象统计学,增加了Kuhn长度、相关长度和蠕虫状链。更多地关注了支化聚合物的特性黏数,特别是聚电解质的特性黏数。

第3篇聚合物在力场中的性质。第10章论及光学性质,更为注重光的反射与透射。第11章论及电学性质,扩展了介电常数与(1)极化、(2)折光率之间的相互关系,以及Debye弛豫。也关注了热释电与驻极体。同时,导电性、聚合物的掺杂与非线性光学也大为扩展。第12章讨论磁学性质,增加了对磁化的介绍,大大增加了对核磁共振(NMR)现象的介绍,以及NMR的检测与弛豫机理(自旋点阵与自旋—自旋)。第13章所论的力学性

能,仍然是聚合物性能中的最重要一类。这次它被大大地扩展了,特别是在橡胶弹性、黏弹性、极限力学性能和单轴取向聚合物(纤维)的力学性能各节。在论及声学性质的第 14 章,扩展了声速对各种参数的依赖性。

第 4 篇聚合物的输运性质。讨论聚合物熔体流变性质的第 15 章,其内容大为扩展,特别是在形变的类型、黏度的定义、聚合物熔体的牛顿剪切黏度、聚合物熔体的非牛顿剪切黏度与第一法向应力系数、聚合物熔体的拉伸黏度、聚合物熔体中的弹性效应及热致液晶聚合物的流变性质各节。论及聚合物溶液流变性质的第 16 章也有了很大扩展,尤其是聚合物溶液在稳态剪切流中的黏弹性、聚合物溶液和溶致液晶聚合物的拉伸流动各节。在分别论述热传导与物质传输的第 17 章中,对热传导和渗透性的介绍稍稍作了扩展。论述结晶与再结晶的第 19 章,对 Avrami 方程和晶核的临界尺寸给予了更多关注。在加工中结构的形成一节作了彻底的修改。在单轴拉伸中的结晶现象:纺丝一节,几个小部分作了扩展。

第 5 篇决定聚合物化学稳定性与崩解的性质。在论述热化学性质的第 20 章,增加了一些从单体到聚合物的反应热力学相关内容,包括聚合的最高温度与最低温度。分别论述热分解和化学降解的第 22 章与第 23 章,只需少许扩展。

第 6 篇整体概念上的聚合物性能。论述加工性能的第 24 章稍有扩展。论述产品力学性能的第 25 章几乎没改动。论述产品环境性能的第 26 章,三节都大大地扩展了。第 27 章最终使用性能的例子并没有改动。

第 7 篇对综合数据表,只改动了一些旁注。

各章的参考文献部分,则是作了大量的更新与补充。

我衷心希望《聚合物的性质》的第四版也能像第三版序言中所说的,"被聚合物界广为认可,证明是一本有用的导则,给众多使用者以帮助"。尽管现在的作者不是有名的 D. W. Van Krevelen 教授,但他在 Delft 技术大学听过多次教授有关《聚合物的性质》的各类讲演。

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K. te Nijenhuis

于荷兰 Dronten

2008 年 8 月

(何嘉松 译)

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I stand at the seashore, alone, and start to think...

There are the rushing
waves mountains of molecules
each stupidly minding its own business
trillions apart
yet forming white surf in unison.

Ages on ages before
any eyes could see
year after year
thunderously pounding the shore as now.
For whom, for what?
On a dead planet
with no life to entertain.

Never at rest
tortured by energy
wasted prodigiously by the sun
poured into space.
A mite makes the sea roar.

Deep in the sea
all molecules repeat
the pattern of one another
till complex new ones are formed.
They make others like themselves
and a new dance starts.

Growing in size and complexity
living things
masses of atoms
DNA, protein
dancing a pattern ever more intricate.

Out of the cradle
onto dry land
here it is
standing:
atoms with consciousness;
matter with curiosity.

Stands at the sea,
wonders at wondering: I
a universe of atoms
an atom in the universe.

Richard P. Feynman (1955)

This book is intended for those who work on *practical* problems in the field of polymers and who are in need of *orienting numerical information* on polymer properties; for the organic chemist who is faced with the task of synthesizing new polymers and wonders if the structures he wants to realize will actually have the properties he has as a target; for the chemical engineer who is often forced to execute his designs without having enough data at his disposal and who looks in vain for numerical values of the quantities needed under the conditions of the process; for the polymer processer who tries to predict and understand how certain physical parameters will react to changes in process conditions; for the polymer technologist who tries to a get a better insight into the interrelations of the many disciplines in his branch; and finally for all students who are interested in the correlation between chemical structure and properties and in the mutual relation of the properties.

With the chemical constitution as the basis, our aim has consistently been to show that each functional group in the molecular structure actually performs a function that is reflected in *all* properties. Ample use has been made of the *empirical fact* that a number of quantities and combinations of quantities have additive properties – within certain limits of precision - so that these quantities can be calculated in a simple manner from empirically derived group contributions or increments. Many readers will be surprised to see how far one can get by setting out from this simple starting point.

Theoretical expositions have purposely been omitted, except where some elucidation is indispensable for a proper understanding of quantities that are less widely known.

It follows that this book has not been written for the polymer scientist proper, notably the polymer physicist and physical chemist, its design being too empirical for him and too much directed to practice. In this book the expert will find no data that are not available elsewhere. Many experts may even have great objections, some of them justified, to the design of this book and its approach.

Unfortunately, the gap between polymer scientists and practicians is not narrowing but constantly widening. The work in the field of polymer science is becoming increasingly sophisticated, in the experimental as well as in the theoretical disciplines.

This book is meant to be a modest contribution towards narrowing the gap between polymer science and polymer practice. Time will have to show whether this attempt has been successful.

On its appearance this book was given such a good welcome that a second edition proved to be necessary within four years. For this purpose the book was completely revised, updated and considerably extended. The scope of the chapters dealing with the mechanical and rheological properties was much enlarged, as where the sections discussing polymer solutions. An improved system for the assessment of the transition temperatures was introduced. SI units are used throughout the book.

While the first impression confined itself to the intrinsic properties, the second edition also covers the processing and product properties, if to a limited extent and on a selective basis.

PREFACE TO THE THIRD EDITION (1990)

Fourteen years passed since the second edition of this book appeared. Since then four new prints were made. As a source of data and for estimations it is now widely used all over the world.

The present Third Edition required a thorough revision and updating, and consequently a certain extension.

The existing subdivision of the book in seven Parts and 27 Chapters remained the same, with one exception: chapter 14. This deals now with a new subject: the Acoustic Properties; its original subject, properties of oriented polymers, is now divided over the chapters 13 and 19.

In the year 2000, Dr Kostas Marinakis, senior acquisitions editor at Elsevier, asked my father to consider the preparation of a revised edition of his *Properties of Polymers*, the handbook that was first published in 1972 and later revised by him twice, in 1976 and in 1990. The proposal pleased him greatly, as this book was still very dear to him.

The unorthodox, practice oriented set-up which he had chosen for the book, by arranging the research findings according to properties, while giving prominence to predictability of properties on the basis of chemical structures, had been very productive and successful. During his long career as a chemical scholar working in industrial research and management, my father had always dedicated himself to bridging technological practice with scientific research, and to combining the insights of all relevant sub-specialties of science and technology.

His other well-known handbook, *Coal* (Elsevier 1961, 1993: 3rd Edition) - fruit of the first twenty years of his professional career - is another clear example of his comprehensive and nearly encyclopaedic approach. He was very much aware of the fact that he still belonged to the generation of classic science authors who aimed at a broad, systematic, coherent presentation of the subject matter. He once said to me that in the future such handbooks like *Coal* and *Properties of Polymers* would not be written anymore by a single person, assuming that there would still be any need for such books in the digital era. Not without nostalgia, he spoke about the things that he had helped to build up, and that had disappeared under his eyes. The glorious coal research activities of DSM, where he had worked from 1940 till 1959, had completely vanished, and the same was true for the innovative research into polymers of AKZO, his pride from 1960 till his retirement in 1976. His two successful handbooks are the only witnesses of those exciting periods of his scholarly life.

The idea that *Properties of Polymers* would get a new life cycle pleased my father immensely therefore, although he was very much aware that he would not be capable to achieve such a huge task alone at the age of 86 years. So he decided to look for a co-author and consulted some of his professional friends. One of them, Dr. Ger Challa, former professor in polymer chemistry at Groningen University, suggested Dr. Ir. Klaas te Nijenhuis to him as a possible co-author. Te Nijenhuis was at that time associate-professor at Delft University of Technology, where he had specialized in polymers.

Te Nijenhuis and my father got very well together, and they agreed to co-operate as soon as possible in the revision of the book. Te Nijenhuis would retire from the university by the end of 2003, so from then on he would have sufficient time to work on his share of the revision. On the 3rd of September 2001, the joint publishing agreement with Elsevier was signed.

Eight days later, however, on the catastrophic 11th of September, my father was struck by a bad brain haemorrhage from which he did not recover. He died on 27th of October 2001.

In the hard weeks of his suffering, he clung to the few moments of hope and joy. Such a moment was the visit of Klaas te Nijenhuis. They discussed the intended revision of *Properties of Polymers,* and Te Nijenhuis told him that in the mean time he also had signed the contract and he promised my father that the 4th edition would be prepared

by him anyway. In the face of death, my father was utterly happy to know that his book would survive.

Dr. te Nijenhuis has kept his word, and he has even managed to do the enormous job alone - brushing aside the sceptical remark of my father that after him nobody could or would do such a thing alone. I want to express my deep gratitude to Dr. te Nijenhuis, also on behalf of my sister Irene and my brothers Hans and Frits, for his marvellous achievement. May this 4th edition of *Properties of Polymers* find its way to many readers and users!

Laurens van Krevelen, LL M

Bloemendaal, The Netherlands
August 2008

Eighteen years have passed since the third edition of this book appeared. Since then it has been reprinted twice and has appeared in a paperback edition (1977). As a source of data and estimations it is still widely used all over the world.

In the early 2000's there was a feeling within "Polymer-The Netherlands" that a revised edition of "PROPERTIES OF POLYMERS" was needed. This was already preceded by a suggestion from Elsevier Science B.V. to Prof. Van Krevelen to consider the preparation of a revised edition of his book. However, because of his age Prof. Van Krevelen did not feel capable of doing all the effort for the preparation of a new edition alone. For that reason he invited me in May 2001 to cooperate in the preparation of the fourth edition. I accepted this honourable invitation hesitantly, knowing that it would be a tremendous amount of work. Our joint discussions with Elsevier Science B.V. resulted in a contract that was signed in the autumn of 2001. Prof. Van Krevelen would support me with his fabulous amount of knowledge and experience. Unfortunately, this was not to be, because on 27th of October of the same year he passed away after a brief illness. I will never forget his radiant face when I told him, visiting him in the hospital on 4th of October, together with his son Laurens, that I also had signed the Elsevier contract. Anyhow, I now had to do the work alone and, indeed, it appeared to be a long and lonesome activity. But the mere thought of his radiant face in all his distress, proved to be a stimulus not only to start, but in particular also to continue this huge task.

The present Fourth Edition has been updated and also, when necessary, extended. However, I did not take the opportunity to change the plan of the book: the existing subdivision of the book in seven parts and 27 Chapters has not been changed. The following shows where small changes were made or where the text was extended greatly.

Part I   *General Introduction: A bird's-eye view of polymer science and engineering.* Chapter 1, dealing with approach and objectives of polymer properties, remained almost unchanged. In Chapter 2, where the typology of polymers is discussed, the milestones (Appendix I) are extended and updated, Nobel prize winners concerning Polymers are added and the development of commercial polymers (Appendix II) is updated. In Chapter 3, where the typology of properties is discussed, only small changes and extensions are made.

Part II   *Thermophysical properties of polymers.* In Chapters 4 and 5, that deal with volumetric properties and calorimetric properties, respectively, only marginal extensions are made. In Chapter 6, on transition temperatures, more attention is paid to the thermodynamics of the glass-rubber-transition. Moreover, the treatment of the calculation of the melting temperature of polymer families with two functional groups in the repeating units is changed in such a way that the agreement between calculated and experimental melting temperatures is better. In Chapter 7, on cohesive properties and solubility, the solubility parameter is compared with the Flory Huggins interaction parameter. Further, temperature dependence of the solubility parameter and the solubility parameter of solvent mixtures are added. In Chapter 8, on interfacial energy properties,

a correction term in the equations for the surface energy and more refined approaches of surface energy contributions with the aid of Lifschitz-Van der Waals interactions are added. In Chapter 9, on conformation aspects and conformation statistics, the Kuhn length, the persistence length and the worm-like chain are added. More attention is paid to the limiting viscosity number of branched polymers and in particular of polyelectrolytes.

Part III *Properties of polymers in fields of force.* In Chapter 10, on optical properties, much more attention is paid to reflection and transmission of light. Chapter 11, on electrical properties, is greatly extended with the relationships between the dielectric constant and (1) polarization and (2) refractive index and with Debye relaxation. Some attention is paid to Thermally Stimulated Discharge (TSD) and electrets. Also electric conductivity, doping of polymers and non-linear optics are greatly extended. In Chapter 12, on magnetic properties, the introduction of magnetism is extended. The introduction of the NMR phenomenon is greatly extended, just as the detection of NMR and the relaxation mechanisms (spin-lattice and spin-spin). Chapter 13, on mechanical properties, still the most important class of polymer properties, is extended greatly, in particular the subchapters Rubber elasticity, Viscoelasticity, Ultimate mechanical properties and Mechanical properties of uniaxially oriented polymers (fibres). In Chapter 14, on acoustic properties, the dependence of sound speed on various parameters is extended.

Part IV *Transport properties of polymers.* Chapter 15, on rheological properties of polymer melts, is greatly extended, in particular the subchapters Modes of deformation and definition of viscosity, Newtonian shear viscosity of polymer melts, Non-Newtonian shear viscosity and first normal stress coefficient of polymer melts, Extensional viscosity of polymer melts, Elastic effects in polymer melts and Rheological properties of thermotropic liquid crystalline polymers. Also Chapter 16, on rheological properties of polymer solutions, is extended quite greatly, in particular the subchapters Viscoelastic properties of polymer solutions in steady shear flow, Extensional flow of polymer solutions and Solutions of lyotropic liquid crystalline polymers. In Chapters 17 and 18, on transport of heat and mass, respectively, the introduction of thermal transport and permeability is extended slightly. In Chapter 19, on crystallization and recrystallization, the Avrami equation and the Critical size of crystal nuclei are paid more attention to. The subsection Aspects of structure formation in processing is completely revised. In the subchapter Crystallization phenomena in uniaxial drawing: fibre spinning, several smaller parts are extended.

Part V *Properties determining the chemical stability and breakdown of polymers.* In Chapter 20, on thermomechanical properties, some thermodynamics of the reaction from monomer to polymer are added, included the ceiling and floor temperatures of polymerization. Chapters 21 and 22, on thermal decomposition and chemical degradation, respectively, needed only slight extensions.

Part VI *Polymer properties as an integral concept.* Chapter 24, on processing properties, is extended slightly. Chapter 25, on mechanical product properties, remained almost unchanged. The three subchapters of Chapter 26, on environmental product properties, are extended quite greatly. Chapter 27 on examples of end use properties remained unchanged.

Part VII *Comprehensive tables* Only marginal changes are made.

The *Bibliographies* of the chapters are updated and extended greatly.

I sincerely hope that also this "fourth" edition of "PROPERTIES OF POLYMERS" will find (following the preface to the third edition) "a good acceptance in the polymer world and that it will prove a useful guide and aid to many users", notwithstanding that the present author is not the well-known Prof. D.W. van Krevelen, but somebody who attended many of his various lectures on "PROPERTIES OF POLYMERS" at Delft University of Technology.

K. te Nijenhuis

Dronten, The Netherlands
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In the preface I already mentioned that rewriting this book would be a long and lonesome activity, but in a family consisting of only two persons this activity is also long and lonesome for the other. I am deeply grateful to my wife Laura that I got the opportunity to do this work and for her stimulus and incredible patience: it has been a very special way to spend together a retirement time.

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