普通高等教育“十一五”规划教材

An Introduction to Molecular Biology with Chinese Translation

英汉对照 分子生物学导论

[美] 西尔维恩 W.勒潘 (Sylvain W.Lapan)
王 勇
编著

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化学工业出版社

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本书是为分子生物学双语教学而编写，适用于高年级本科学生使用。本书由10章组成，内容涵盖分子生物学的中心问题，即DNA复制、转录、翻译和重组。我们从该领域的最基本内容（生物大分子的结构与功能）开始，系统、完整地阐述了上述主题，并引领读者贯通现代知识体系，从而深入理解这些过程是如何进行调控并创造出我们称之为“生命”的动态系统的。我们有目的地使用简洁的语言和详尽的插图来强化双语教学。所附CD含有名词解释、各章节的英语音频录音以及彩色插图，由此进一步强化双语教学目标。CD中还包含一些关于重要实验技术的内容，可以帮助学生将课堂所学分子生物学知识与课外学习活动联系起来。通过提供关于分子生物学重要内容和相关领域专业英语方面的训练，本教材能真正为读者提供一种现代的、切合实际的学习方式。

图书在版编目（CIP）数据

英汉对照分子生物学导论/[美] 勒潘（Lapan，S. W.），王勇编著. —北京：化学工业出版社，2008.1

普通高等教育“十一五”规划教材

ISBN 978-7-122-01485-6

Ⅰ. 英… Ⅱ. ①勒…②王… Ⅲ. 分子生物学-高等学校-教材-英、汉 Ⅳ. Q7

中国版本图书馆CIP数据核字（2007）第177939号

责任编辑：赵玉清　　　　文字编辑：刘　畅

责任校对：王素芹　　　　装帧设计：韩　飞

出版发行：化学工业出版社（北京市东城区青年湖南街13号　邮政编码100011）

印　　刷：北京永鑫印刷有限责任公司

装　　订：三河市万龙印装有限公司

787mm×1092mm　1/16　印张16½　字数444千字　　2008年1月北京第1版第1次印刷

购书咨询：010-64518888（传真：010-64519686）　　售后服务：010-64518899

网　　址：http://www.cip.com.cn

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定　　价：32.00元

Preface

One of the wonderful things about molecular biology is that the field depends on constant communication. Important questions can only be answered through the collaboration of researchers from all over the world, who each contribute their piece of the puzzle and build on each other's work. But this lively interaction also poses challenges, particularly the problem of language. How can scientists collaborate if they speak and publish in different languages?

As it happens, the language of molecular biology is now English. The vast majority of published research is in English, as are most international conferences. The language has become so central because a large number of scientists and research centers that have made important contributions to molecular biology were, and still are, based in England and the United States. The predominance of one language is not necessarily fair, but it is a reality that most professionals working in the field must face.

For Chinese students, learning biology in English can be very exciting, but also quite challenging. Chinese and English are very different languages, with completely different phonetics and writing systems. On top of this, biology textbooks and articles in English are especially difficult to understand, even for native English speakers. There is a lot of unique vocabularies, and there may be sentence structures particular to scientific writing.

In many cases, Chinese students are presented with a giant textbook only in English and instructors hope for the best. Our experience as teachers of molecular biology in China is that this approach

前　言

关于分子生物学的美好事物之一就是这一领域的发展依赖于不断的交流。重大问题只能通过全世界研究人员的合作才能找到答案，每个研究小组为解答难题贡献出他们的研究成果，并在他人研究成果的基础上开展更深入的研究。但是要开展这种密切合作也面临着许多挑战，特别是语言问题。如果科学家们说着不同的语言、用不同的语言发表文章，那他们之间怎么去开展合作呢?

算是一种机缘巧合吧，现在分子生物学所用的语言是英语。绝大多数研究结果都用英语发表，大多数国际会议也用英语发言。由于对分子生物学做出过重大贡献的许多科学家和研究中心都在英国和美国，现在也仍然是这些国家在发挥着主导作用，因此英语已经成为首要的语言。一种语言起主导作用不一定是公平的，但这是大多数在这一领域工作的专业人员必须面对的现实。

对中国学生来说，用英语学习生物学会是很令人兴奋的，但也会是颇具挑战性的。汉语和英语是很不一样的语言，具有完全不同的语音和语法体系。此外，生物学的英语教材和文章特别难以理解，即使对母语为英语的读者来说也是如此。书中有许多特殊的词汇，还会有一些特殊的科技写作方面的惯用句子结构。

许多时候，中国学生拿到手的是一本厚厚的英文教材，教师希望学生从中获得最大的收益。我们在中国讲授分子生物学的体会是：这样的做法是不

is unrealistic. Most students in China at this time, especially those who are on a course of scientific study, do not have enough training in English to understand textbooks written for native English speakers. Struggling with the language often comes at the expense of actually learning the concepts and principles of molecular biology.

切合实际的。这一阶段的大多数中国学生，特别是那些还处于科学研究课程学习阶段的学生，并不具备足够的英语能力去理解为母语是英语的读者编写的教材。在语言上的些许进步实际上是以牺牲理解分子生物学概念与原理为代价的。

We have put together this book with the hope of creating a more realistic, more sympathetic, and more specialized approach to learn molecular biology in English. Advanced students can learn by reading the English portion of the book, and refer to the Chinese translation to check their understanding, or for reference on individual words. Beginners in English can learn from the Chinese portion, and refer to the English for an introduction to vocabularies. With both languages present, students and instructors have more options for how to learn!

我们编写此书的目的是想为用英语学习分子生物学提供一种更实际、更让人喜欢和更专业的方法。程度好的学生可以阅读本书的英文部分，并参考中文译文以检查他们的理解情况，或参考个别单词的中文含义。英语程度差一点的学生可以从本书的中文部分学习，并参考英文而开始掌握专业词汇。使用这样的英汉对照教材，在如何学习上学生和教师都可以有更多的选择！

An added feature of this book is that all the English texts and vocabularies have been accompanied by audio files. They are especially helpful for those who intend to improve their listening comprehension of academic English. Meanwhile, the elaborately designed figures will enable readers to understand concepts and principles in molecular terms much more easily.

本书的另一个特点是：所有的英语课文和词汇都有配套的音频文件。它们对那些希望提高自身专业英语听力水平的人特别有帮助。同时，精心设计的插图能使读者更容易地从分子水平上理解相关的概念与原理。

The book covers the material that we feel an advanced, undergraduate student of molecular biology should know. Unlike many textbooks used for molecular biology, this is not meant as a reference book, a large volume where one can look up any facts about the cell. Those kinds of volumes have their use, but we feel that it is unproductive to present students with such piles of information. If students can master all of the information present even in this relatively brief book, they will already be more informed than most students of the field, and even some professionals!

本书包括的内容是我们认为一个分子生物学高年级本科生应该掌握的。与许多分子生物学教材不同，它不是一本参考书，不是一本让人查阅关于细胞各方面内容的大部头著作。那些大部头著作自然有它们的用武之地，而我们觉得向学生提供这么一大堆信息并不是很有成效的做法。如果学生能掌握这本相对来说比较简单的书中的所有内容，他们就已经是这一领域学生中出类拔萃的了，他们甚至可能比一些专业人员还要强！

It is with great excitement that we invite you to learn molecular biology with us in English. This is an important age for China and the rest of the world! As China becomes every day more prosperous, its research centers and companies are improving and have much to offer scientific communities around the world. At the same time, the continued development of China depends on the knowledge and skills that have been developed in the West and continue to flourish there. In molecular biology, there is much to gain if we can share and communicate with each other!

能邀请你与我们一道用英语来学习分子生物学让我们觉得很兴奋。中国和世界的其他国家正处于一个重要的时代！随着中国的日益进步与繁荣，中国的研究中心和公司正在取得更大的进展，它们正在为世界科学共同体提供更多的研究成果。同时，中国的持续发展需要了解西方已经拥有的和即将涌现的知识和技能。在分子生物学领域，如果我们能够共享知识与技能并互相交流，我们就都可以取得更大的成就！

Sincerely,
The Authors

October 2007

作者　谨识

2007 年 10 月

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Introduction

We say a cell is alive. But look inside a cell and all you will see are molecules, collections of atoms that are as inanimate as the paper of this book. How does a set of objects make a dynamic living organism? This question is the basis of the field of molecular biology.

The most fundamental features shared by all known life are the ability to reproduce and the ability to grow. If organisms were not able to reproduce, life would be impossible. Perhaps once in a billion years a precursor to life could arise spontaneously from a pool of chemicals; but if this form could not make more of itself, it would soon vanish. The necessity to grow is a direct result of the necessity to reproduce. As one cell makes two and two cells make four, for example, the mass of the original cell becomes more and more divided. If the offspring do not grow, after several generations they will be impossibly small.

So how can a set of molecules reproduce and grow? These functions are largely the work of large molecules called proteins, nature's tiny machines. For reproduction, proteins copy some parts of the cell, and pull one cell apart to make two cells. For growth, they can take in nutrients from the environment and put these nutrients together to make the structures of the cell. They also break down nutrients to provide the energy and molecular building blocks. Proteins are able to undertake so many tasks because of their large size, intricate three-dimensional structures, and complex chemical properties.

But proteins are not the end of the story. Proteins cannot directly reproduce themselves; therefore, they cannot be solely responsible for life. The formation of proteins depends on another kind of molecule called nucleic acids. Nucleic acids, mainly DNA, are especially well-suited for carrying the information to make proteins. DNA

绪论

我们说一个细胞是活的。但是往细胞里面看，所有你看到的都是分子和各种各样的原子，它们就像本书的纸张一样没有生命。这样一些物体怎么会产生动态的生命呢？这是分子生物学领域所要研究的基本问题。

所有已知生命都具有的最基本特征是它们能够繁殖和生长。如果生物不能繁殖，生命就不可能存在。也许在十亿年里从一些化学物质中会自发出现生命的原始形式；但如果这一形式不能繁殖的话，它很快就会消失。生长的必要性是繁殖必要性的直接结果。例如，当一个细胞产生两个、两个细胞产生四个的时候，原始细胞的物质一次又一次地被分开。如果子代细胞不能生长的话，那么要不了几代细胞就会小到不可思议。

那么，这样一些分子是怎样繁殖和生长的呢？答案是：这些功能主要是由蛋白质这样的大分子来完成的，它们是自然界的微型生产机器。对繁殖来说，是蛋白质对细胞的某些部分进行了复制，并使一个细胞分裂产生两个细胞。对生长来说，是蛋白质把营养物质从环境中带进来，并用它们建造出细胞的各个组成部分。它们也分解营养物质产生能量和分子结构组件。蛋白质能够承担各种各样的任务，其原因就是它们具有较大的体积、精巧的三维结构和复杂的化学性质。

但是蛋白质并不是故事的结尾。蛋白质不能直接繁殖它们自身；因此，光有蛋白质还不足以实现所有的生命机能。蛋白质的形成依赖于另一种称为核酸的分子。核酸当中的一种即 DNA 特别适合携带生产蛋白质的信息。DNA 也从每

is also passed down with each new generation, allowing offspring to completely reproduce the set of proteins present in the parent. If proteins are the cell's machines, DNA is the cell's head engineer-knowledgeable about how to make the machines, and able to pass this knowledge from generation to generation.

个世代传递到下一世代中，使子代能够生产所有在亲本中出现的蛋白。如果蛋白质是细胞的机器，那么细胞中的DNA就是总工程师——它们知道应该怎样生产机器，还能将这种知识一代一代地传递下去。

In order to make proteins, DNA is copied using another nucleic acid, called RNA. This process is called **transcription.** RNA is then used as a guide to put together the small molecules that make a protein, a process called **translation.** This general progression, DNA→RNA→Protein, is used in all life forms. Because it is so central to molecular biology, it has been termed the **central dogma.**

为了生产蛋白质，需要用到另外一种核酸即RNA来拷贝DNA。这一过程称为**转录**。之后，RNA用来作为引导者将小分子放在一起来产生蛋白质，这是一个称为**翻译**的过程。这种一般的进程，即DNA→RNA→蛋白质，被所有生命形式所采用。由于它对分子生物学是如此重要，以至于称它为**中心法则**。

The general scheme of the central dogma is very basic, and many details need to be filled-in. The work of adding these details is spread between different fields of biology, of which molecular biology is just one. Molecular biology is most focused on the question of how nucleic acids and proteins are used to make more proteins. Other fields have different emphases. For example, genetics is focused particularly on the structure, function and inheritance of genes. Cell biologists may study how proteins and other molecules form the structures of the cell, how the cell divides, and how it interacts with the environment. Biochemistry has a classic focus on metabolic pathways in the cell and the enzymatic roles of proteins. Generally, these and other fields overlap to a great extent, and there is no saying where exactly one ends and one begins.

中心法则的一般过程看上去很简单，但我们应该知道其中的许多细节。探询这些细节的工作分散在生物学的不同领域中，分子生物学是其中之一。分子生物学主要关注核酸和蛋白质如何用来生产更多的蛋白质。其他领域则各有其侧重点。例如，遗传学特别注重基因的结构、功能和遗传。细胞生物学家们可能会研究蛋白质和其他分子怎样形成细胞的结构、细胞怎样分裂、它如何与环境进行相互作用。生物化学则对细胞中的代谢途径和蛋白质的酶学作用更为关注。一般情况下，这些领域之间在很大程度上会有重叠，说不清某个领域的研究范围从哪儿开始、在哪儿结束。

Although the topic of molecular biology as stated here may seem somewhat simple, many details must be mastered to truly understand the depth of the field. It is easy to get lost in these details, and so before we discover them, we lay out some guiding principles that can give a sense of order to many of these intricacies. Most important are the forces that shape life, including evolution, physics, and the availability of resources.

虽然这里所说的分子生物学主题看起来有些简单，但若要真正理解这一领域深层次的东西，还是必须掌握许多细节内容。而一旦深入到细节中又很容易迷失方向，因此在开始学习之前，我们列出几条指导原则来帮助梳理许多这样的细节。这当中最重要的是那些塑造了生命的力量，包括进化、物理学和可利用资源。

All life forms are the product of evolution. Life today is far too complicated to have arisen spontaneously from

所有生命形式都是进化的产物。今日的生命太复杂以至于不可能从简单的分子自发

simple molecules. Its present complexity can be understood by the accumulation of small advantageous changes over long periods of time. Because evolution is based on chance, new improvements in an organism generally arise as relatively modest changes to a previous state. Always remember, the mechanisms in a cell are not necessarily the best possible; they are the currently best improvement over a pre-existing state.

地出现在我们面前。它现在所具有的复杂性可以被理解成是在漫长的时光里一点一滴地积累了小的有利变化的结果。由于进化是有机会性的，一种生物中的新改进一般只是相对于先前的状态来说稍有变化而已。请总是记住一点：细胞中的某种机理不一定是所有可能性中最好的；相对于先前的状态而言，它们只是针对目前的情况而做出的最佳改进。

All life on Earth appears to have evolved from a common ancestor. One of the descendants of that ancestor had a life strategy so successful that it remained mostly unchanged in the evolution of millions of species over billions of years. That strategy has, at its core, the production of proteins from DNA using an RNA intermediate. The changes evolved by the millions of species that descended from that ancestor were, from a morphological perspective, enormous-leading to dinosaurs on the one hand, and bacteria on the other. From the perspective of molecular biology, however, the evolutionary changes were icing on the cake; all life forms retained the central dogma. As a consequence, in molecular biology we are able to make very relevant comparisons between distant life forms, like humans and bacteria.

地球上所有的生命看起来都是从一个共同的祖先进化来的。那一祖先的后代之一具有一种生命策略，它是如此成功以至于在几十亿年的进化史中进化出来的几百万种生物中基本保持不变。作为它的核心，这一策略就是使用 RNA 作为从 DNA 生产蛋白质的中介物。从外观上看，来自于共同祖先的几百万种生物在进化上是如此不同——它们大的像恐龙那样大，小的又像细菌那么小。而从分子生物学的角度看，进化所产生的改变不过是蛋糕上的装饰而已；所有生命形式都遵循中心法则。因此，在分子生物学中我们能够对亲缘关系很远的生命形式做出相关比较，例如我们可以比较人类和细菌之间的异同点。

In addition to sharing a common ancestor, all life on earth is subject to the same set of physical laws; like all matter, the molecules that make life are subject to the laws of physics. Motion and attraction of these molecules, for example, are guided and limited by strict rules. In the universe, all things tend to become more disordered, a property called entropy. Cells are highly ordered structures that must overcome the disorder of entropy by using energy. However, energy is always conserved in the universe. In order for a cell to obtain more energy, it must take energy from someplace else. The acquisition of energy and its efficient usage are necessities that fundamentally shape living things.

除了拥有共同的祖先之外，地球上的所有生命都服从相同的物理学定律；像所有物质一样，组成生命的分子也服从物理学定律。例如，它们的分子运动与相互吸引受到物理学定律的严格指导和限制。在宇宙中，所有事物都倾向于变得更无序，这是一种称为熵的性质。细胞是高度有序的结构，必须利用能量去克服熵的无序。然而，能量在宇宙中总是守恒的。细胞为了能够有更多的能量可供使用，它必须从别的地方获得能量。生物必须具备获得能量并加以有效使用的能力，这是生命现象的最基本体现。

Available energy is only one example of a resource that is limited in the environment. Molecular building blocks of cellular components are another. The limited availability of

可利用的能源只是环境中限制性资源的一个例子。细胞成分的分子部件是另一种限制性资源。资源的限制性意味着：

certain resources means that many cellular mechanisms are shaped by a need to be efficient. Cells can not perform whatever task with whatever material. In some cases, better molecules are imaginable for the cellular tasks at hand, but these molecules are unattainable.

许多细胞机理是为了有效地使用资源而塑造出来的。细胞并不能随心所欲地使用任何材料来执行任何任务。有的时候，细胞倒是想用更好的分子去完成手头的任务，但这些分子往往得不到。

Within these guidelines, and many others, life on Earth has been able to find many solutions. Evolution, though slow and blind, has been a very powerful source of change over the course of billions of years of Earth's history. Within the laws of physics, life has been able to create order from a disordered mixture of chemicals-largely thanks to energy provided by the sun. Chemical building blocks, such as carbon, that are the basis for complex, functional structures are widely available on Earth. Also, the presence of liquid water on the planet has provided an ideal medium for chemical processes on which life is based.

在诸如此类指导原则的框架内，地球上的生命找到了许多解决方案。进化虽然发生得极为缓慢而且盲目，但在地球存在的几十亿年历史过程中，它却是非常有效的获得解决方案的源泉。在物理学定律的限制下，生命从无序的化学物质混合物中创造出了有序的结构——这还应感谢太阳提供的能量。一些像碳原子这样的化学元素在地球上很容易获得，它们是组成具有复杂功能结构的基础。此外，地球上液态水的存在为生命赖以生存的化学过程提供了理想的介质。

In the following chapters of this book, we invite you to learn how inanimate molecules have come together to create life, steering between the limitations and the advantages provided by our planet and our universe.

在本书的后续章节中，我们邀请你来学习这些无生命的分子是如何组合在一起创造出生命的，它们又是如何在地球以及宇宙所提供的不利条件与有利条件之间曲折前行的。

Chapter 1 Amino Acids to Proteins

Life is most directly the work of **proteins.** Proteins allow organisms to grow and reproduce, the most fundamental properties of life. They provide shape and strength, and in many cases movement. They underlie cellular communication, but are also a key part of the boundaries that separate cells and organelles from their environment. In the cell, proteins are everywhere and do almost everything. In this chapter we examine the molecular composition of proteins, showing how the joining of small, simple molecules can produce large molecules with complicated shapes and extraordinary functions.

1.1 Protein Composition

Proteins are **polymers** of small molecules called **amino acids** (Figure 1.1). It is convenient to think of an amino acid as a carbon atom attached to four different chemical groups. Three of these are all always the same: an **amino group**, a **carboxyl group**, and a hydrogen atom. The fourth group is generally termed the side chain, or **R group**, and varies between different amino acids. There are 20 different amino acids commonly used to make proteins, and all 20 have different R groups. R groups have various sizes and chemical properties (Figures 1.2 and 1.3).

第1章 从氨基酸到蛋白质

生命几乎就是**蛋白质**的杰作。蛋白质让生物得以生长和繁殖，生长和繁殖是生命最基本的特征。蛋白质赋予了生物外形和力量，以及在许多情形中的运动功能。蛋白质还是细胞通讯的基础，也是细胞膜的组成部分（正是细胞膜将细胞和细胞器与它们的环境分隔开）。在细胞中，蛋白质无处不在，行使着几乎所有功能。本章我们将学习蛋白质的分子组成，了解简单小分子是如何连接在一起产生具有复杂形状和超乎寻常功能的大分子的。

1.1 蛋白质的组成

蛋白质是由称为**氨基酸**的小分子组成的**聚合物**（图 1.1）。可以很方便地把氨基酸看成是由四个不同的化学基团连接到一个碳原子上而形成的结构。其中三个基团总是相同，即**氨基**、**羧基**和氢原子。第四个基团通常被称为侧链，或 **R 基团**，它随氨基酸的不同而有变化。通常有 20 种不同的氨基酸被用来生产蛋白质，它们均具有不同的 R 基团。R 基团大小不一，其化学性质也不同（图 1.2 和图 1.3）。

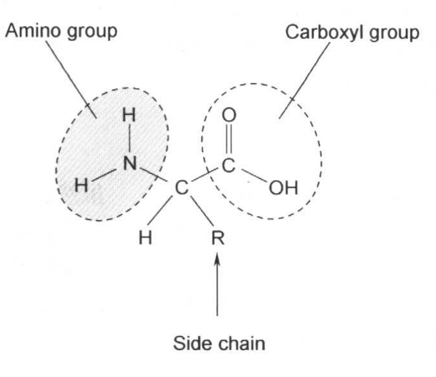

Figure 1.1 General amino acid structure

图 1.1 氨基酸的一般结构

Hydrophobic R groups 疏水的 R 基团			
Glycine	甘氨酸	Gly	G
Alanine	丙氨酸	Ala	A
Isoleucine	异亮氨酸	Ile	I
Leucine	亮氨酸	Leu	L
Methionine	甲硫氨酸	Met	M
Phenylalanine	苯丙氨酸	Phe	F
Tryptophan	色氨酸	Trp	W
Proline	脯氨酸	Pro	P
Valine	缬氨酸	Val	V
Acidic R groups 酸性的 R 基团			
Aspartic acid	天冬氨酸	Asp	D
Glutamic acid	谷氨酸	Glu	E

Hydrophilic R groups 亲水的 R 基团			
Serine	丝氨酸	Ser	S
Threonine	苏氨酸	Thr	T
Asparagine	天冬酰胺	Asn	N
Glutamine	谷氨酰胺	Gln	Q
Cysteine	半胱氨酸	Cys	C
Tyrosine	酪氨酸	Tyr	Y
Basic R groups 碱性的 R 基团			
Arginine	精氨酸	Arg	R
Histidine	组氨酸	His	H
Lysine	赖氨酸	Lys	K

Figure 1.2 The twenty amino acids and their abbreviations

图 1.2 20 种氨基酸以及它们的缩写表示法

Amino acids are joined to each other by combining the amino end of one with the carboxyl end of another (Figure 1.4). Because all amino acids have these two ends, any amino acid can join to any other amino acid. The polymer that results from these combinations is linear, meaning that there are no branchpoints. Proteins can be composed of any combination of the twenty amino acids, in any number, attached in any order. In fact, this flexibility in composition is necessary to produce the wide variety of proteins that are used in nature.

氨基酸可以通过一个氨基酸上的氨基与另一个氨基酸上的羧基结合而互相连接起来（图 1.4）。由于所有氨基酸都具有这两个基团，因此任何氨基酸都可以与任何其他氨基酸相连接。这种结合形成的聚合物是线性的，意味着它们没有分支。蛋白质可以由 20 种氨基酸以任何组合、任何数目和任何顺序组成。事实上，这种在组成上的灵活性对于产生在自然界中用到的种类繁多的蛋白质是必需的。

The bond that joins two amino acids in a protein is called a **peptide bond**. It is a kind of amide bond. The peptide bond is quite strong and rigid, and does not allow rotation. This is because the double-bond joining the carbon and oxygen is also distributed between the same carbon and the adjacent nitrogen. The redistribution of electron density gives a partial double-bond character to the carbon-nitrogen bond, which is the core component of the peptide bond. This **partial double-bond** character prevents the peptide bond from rotating easily.

在蛋白质中连接两个氨基酸之间的键叫做**肽键**。它是一种酰胺键。肽键很强并具有刚性，不允许旋转。这是因为连接碳和氧的双键也在同一个碳和邻近的氮之间进行分配。电子密度的重新分布使得碳-氮键具有部分双键的特性，而碳-氮键是肽键的核心成分。这种**部分双键**特性防止了肽键发生自由旋转。

Although peptide bonds are rigid, amino acid chains are flexible because other bonds within each of the amino acids can rotate (Figure 1.5). As a result, although proteins are linear, they are not one-dimensional. The linear molecule bends, folds, and twists to form complicated three-dimensional structures. We explore protein structures in the next section.

虽然肽键具有刚性，但是氨基酸链还是容易弯曲的，因为位于氨基酸里面的其他键都可以发生旋转（图 1.5）。结果，虽然蛋白质是线性的，但它们并不是一维的。线性的分子会发生弯曲、折叠和扭曲从而形成复杂的三维结构。我们将在下一节中去探寻蛋白质结构方面的知识。