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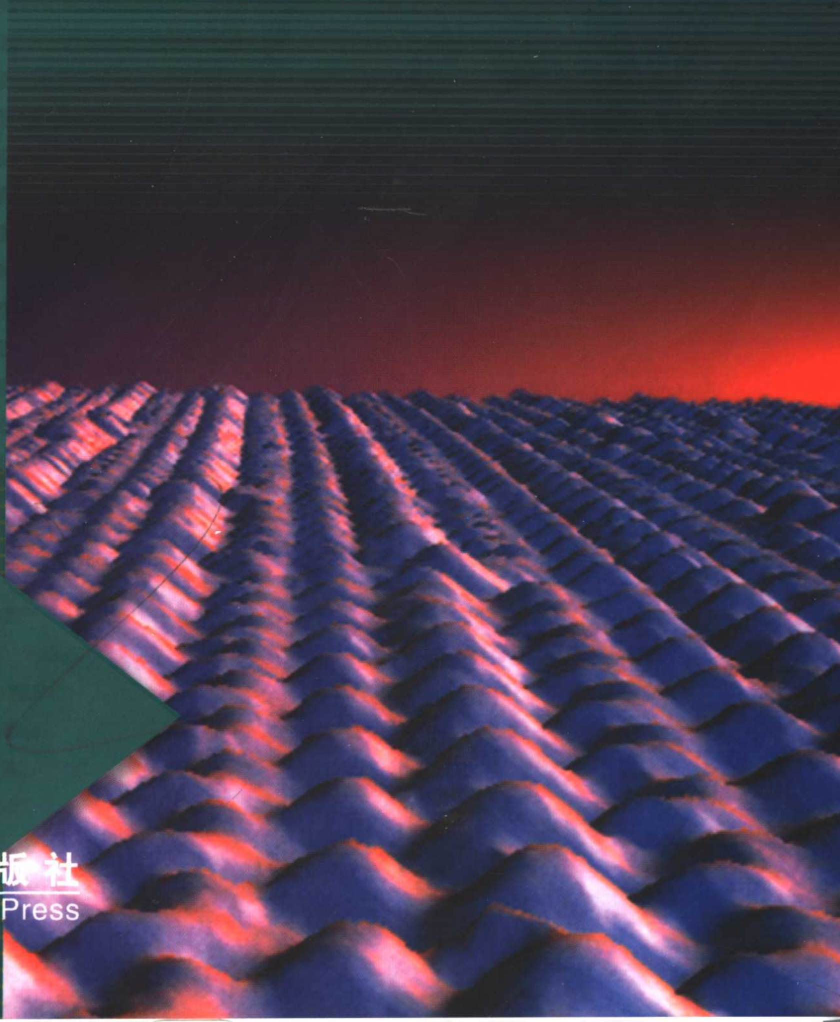
Modern Physics
近代物理学

□ J. BERNSTEIN　P. M. FISHBANE　S. GASIOROWICZ 原著
□ 史斌星 改编



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Higher Education Press

图字：01-2004-6700号

图书在版编目(CIP)数据

近代物理学 = Modern Physics：改编版/(美)伯恩斯坦(Bernstein,J.),(美)菲什波恩(Fishbane, P. M.),(美)高斯奥沃茨(Gasiorowicz,S.)原著；史斌星改编. －北京：高等教育出版社，2005.6
ISBN 7－04－016451－5

Ⅰ.近...　Ⅱ.①伯...　②菲...　③高...　④史...
Ⅲ.物理学－高等学校－教材－英文　Ⅳ.O41

中国版本图书馆 CIP 数据核字(2005)第 020721 号

出版发行	高等教育出版社	购书热线	010－58581118
社　　址	北京市西城区德外大街 4 号	免费咨询	800－810－0598
邮政编码	100011	网　　址	http://www.hep.edu.cn
总　　机	010－58581000		http://www.hep.com.cn
		网上订购	http://www.landraco.com
			http://www.landraco.com.cn
经　　销	北京蓝色畅想图书发行有限公司		
印　　刷	北京民族印刷厂		
开　　本	787×1092　1/16	版　　次	2005 年 6 月第 1 版
印　　张	32.75	印　　次	2005 年 6 月第 1 次印刷
字　　数	800 000	定　　价	54.00 元

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物料号　16451－00

内容简介

本书是Jeremy Bernstein等编著的Modern Physics (Pearson出版集团，2000年出版)的改编版。本书的原版本内容丰富，资料翔实，涉及物理学领域的最新成果和研究课题，在国外被许多院校指定或推荐给学生作为近代物理学的主要参考书，具有比较大的影响。本书根据国内教学实际，删去了原版第一篇“狭义相对论”部分，保留了“量子力学”、“物理应用”和“物理前沿”的大部分内容。本书详细阐述了量子力学发展的历程和取得的成就，涉及复杂原子与分子、统计物理、原子辐射与激光、导体、半导体与超导体、原子核等内容以及基本粒子物理等一些前沿领域。

本书可供普通高等学校理科物理类专业作为双语教学教材使用，也可供其他专业和社会读者参考。

出版者的话

为适应当前我国高等学校各类创新人才培养的需要，大力推进教育部倡导的双语教学，配合教育部实施的“高等学校教学质量与教学改革工程”和“精品课程”建设的需要，国内一些出版社都陆续原版引进了不少海外优秀教材。海外优秀教材的立体化配套、多种教学资源的整合，以及为课程提供的整体教学解决方案，都有不少值得我们学习借鉴之处。但一个不容忽视的问题是，外文原版教材与我国现行的课程内容、教学体系、教学习惯等存在着巨大的差异性。譬如，重点课程的原版教材通常很厚，内容很多，容量是国内自编教材的好几倍。国外的情况是，老师未必会都讲，剩下大量的内容留给学生自学；而国内的情况不尽相同。受国内教学学时所限，完全照搬是不合时宜的。教材的国际化必须与本民族的文化教育传统相融合，在原有的基础上吸收国外优秀教材的长处，这使得我们需要对外文原版教材进行适当的改编。改编不是简单地使内容减少，而是结合国内教学特点，引进国外先进的教学模式及思想，在教学内容和方式上更中国化，使之更符合国内的课程设置及教学环境。

2004年伊始，高等教育出版社有计划、大规模地开展了海外优秀理科系列教材的引进及改编工作。在引进改编海外优秀教材的过程中，我们坚持了两条原则：(1)精选版本，打造精品系列；(2)慎选改编者，保证品质。

首先，我们和Pearson Education，John Wiley & Sons,McGraw-Hill以及Thomson Learning等国外出版公司进行了广泛接触，经推荐并在国内专家的协助下，提交引进版权总数200余种，学科专业领域涉及数学、物理、化学化工、地理、环境等。收到样书后，我们聘请了国内高校一线教师、专家学者参与这些原版教材的评介工作，从中遴选出了一批优秀教材进行改编，并组织出版。这批教材普遍具有以下特点：(1)基本上是近几年出版的，在国际上被广泛使用，在同类教材中具有相当的权威性；(2)高版次，历经多年教学实践检验，内容翔实准确，反映时代要求；(3)各种教学资源配套整齐，为师生提供了极大的便利；(4)插图精美，丰富，图文并茂，与正文相辅相成；(5)语言简练，流畅，可读性强，比较适合非英语国家的学生阅读。

其次，慎选改编者。原版教材确定后，随之碰到的问题是寻找合适的改编者。要改编一本教材，必须要从头到尾吃透它，有这样的精力自编一本教材都绰绰有余了。我们与国内众多高等院校的专家学者进行了广泛的接触和细致的协商，几经酝酿，最终确定下来改编者。大多数改编者都是有国外留学背景的中青年学者，他们既有相当高的学术水平，又热爱教学，长期工作在教学第一线。他们了解引进版教材的知识结构、表达方式和写作方法，最重要的是他们有时间，有精力，有热情，有的甚至付出了比写一本新教材更多的劳动。我们向他们表示最真诚的敬意。

在努力降低引进教材售价方面，高等教育出版社做了大量和细致的工作，这套引进改编的教材体现了一定的权威性、系统性、先进性和经济性等特点。

这套教材出版后，我们将结合各高校的双语教学计划，开展大规模的宣传和培训工作，及时地将本套丛书推荐给各高校使用。在使用过程中，我们衷心希望广大教师和学生提出宝贵的意见和建议。如有好的教材值得引进，也请与高等教育出版社高等理科分社联系。联系电话：010－58581384(数学)；010－58581374(物理)；010－58581380(化学化工)。E-mail:xuke@hep.com.cn。

高等教育出版社

2004年10月

Fundamental Constants

speed of light (definition)	c	2.9979×10^{8} m/s
elementary charge	e	1.6021×10^{-19} C
Planck's constant	$\hbar$	1.0546×10^{-34} J·s
		6.5821×10^{-22} MeV·s
	$h = 2\pi\hbar$	6.6261×10^{-34} J·s
gravitational constant	G	6.6726×10^{-11} m³/(kg·s²)
Planck time	$\sqrt{\hbar G/c^5}$	5.4×10^{-44} s
fine structure constant	$\alpha = \dfrac{e^2}{4\pi\varepsilon_0\hbar c}$	1/137.036
	$\hbar c$	197.33 MeV·fm
		3.162×10^{-28} J·m
electron mass	m_e	9.1094×10^{-31} kg
proton mass	m_p	1.6726×10^{-27} kg
neutron mass	m_n	1.6749×10^{-27} kg
electron rest energy	$m_e c^2$	0.5110 MeV
proton rest energy	$m_p c^2$	938.28 MeV
neutron rest energy	$m_n c^2$	939.57 MeV
proton-electron mass ratio	m_p/m_e	1836.15
Bohr radius	$a_0 = \dfrac{\hbar}{m_e c\alpha}$	0.5292×10^{-10} m
Rydberg constant	$Ry = \dfrac{(m_e c^2)\alpha^2}{4\pi\hbar c}$	1.0974×10^{7} m⁻¹
Compton wavelength of electron	$\dfrac{\hbar}{m_e c}$	3.8616×10^{-13} m
Boltzmann constant	k	1.3807×10^{-23} J/K
universal gas constant	R	8.3145 J/(mol·K)
Avogadro's number	N_A	6.022×10^{23} mol⁻¹
Bohr magneton	$\mu_B = \dfrac{e\hbar}{2m_e c}$	9.2740×10^{-24} A·m²
magnetic flux quantum	$\Phi_0 = h/2e$	2.0678×10^{-15} T·m²

Other Constants

Stefan–Boltzmann constant	σ	5.68×10^{-8} W/(m²·K⁴)
Acceleration of gravity	g	9.807 m/s²
Solar mass	M_e	1.989×10^{30} kg
Solar radius	R_e	6.96×10^{8} m
Earth mass	M_E	5.976×10^{24} kg
Earth radius	R_E	6.374×10^{6} m
Earth-Sun distance (mean radius)	AU	1.496×10^{11} m
Earth-Moon distance (mean radius)		3.844×10^{8} m
Hubble parameter	H	2.5×10^{-18} s⁻¹
Volume of a mole of ideal gas at STP		22.414 liters
Air density at STP		1.293 kg/m³
Triple point temperature of water		273.16K

Conversions and Equivalents

1 degree = 1.745×10^{-2} rad (360 degrees = 2π rad)
1 fermi = 10^{-15} m
1 lt-yr = 9.46×10^{15} m
1 parsec = 3.09×10^{16} m
1 inch = 2.54 cm
1 mile = 1.609 km
1 eV = 1.6022×10^{-19} J
1 calorie = 4.1086 J
1 kWh = 3.6×10^{6} J
$kT \cong 1/40$ eV at room temperature (293K)
1 gauss = 10^{-4} T
1 atomic mass unit $u = 1.661 \times 10^{-27}$ kg
energy equivalent of 1 $u(= uc^2) = 931.5$ MeV
1 atm = 1.013×10^{5} Pa
1 Ci = 3.7×10^{10} decays/s

Some formulas

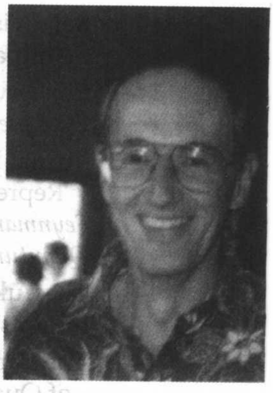
Relativistic gamma factor	$\gamma = \dfrac{1}{\sqrt{1 - v^2/c^2}}$
relativistic momentum	$p = \gamma m\vec{v}$
relativistic energy	$E = \gamma mc^2 = (p^2c^2 + m^2c^4)^{1/2}$
relativistic velocity	$\vec{v} = \vec{p}c^2/E$
Bohr model energies of electrons in hydrogen	$E_n = -hc\dfrac{Ry}{n^2} = -\dfrac{m_e c^2\alpha^2}{2n^2}$
Bohr model radii of hydrogen electronic orbits	$n^2 a_0$
de Broglie wavelength	$\lambda = h/p$
Schrödinger equation	$-\dfrac{\hbar^2}{2m}\left(\dfrac{\partial^2}{\partial x^2} + V(x)\right)\psi(x,t) = i\hbar\dfrac{\partial\psi}{\partial t}$
position-momentum uncertainty principle	$\Delta x \Delta p \geq \hbar/2$
time-energy uncertainty principle	$\Delta t \Delta E \geq \hbar/2$
Boltzmann factor	$\exp(-E/kT)$
Fermi energy (nonrelativistic)	$E_F = \dfrac{\hbar^2\pi^2}{2m}\left(\dfrac{3n}{\pi}\right)^{2/3}$
Schwarzchild radius	$R_S = \dfrac{2GM}{c^2}$

About the Authors

Jeremy Bernstein

Jeremy Bernstein has had a dual career in physics and writing. He was on the staff of the *New Yorker* from 1963 to 1993 and was a Professor of Physics at the Stevens Institute of Technology from 1968 until his retirement in 1993, when he became Professor emeritus. He has won several awards for his writing about science and mountain travel. He has also published widely in both technical and non-technical journals. Some of his recent books are: *An Introduction to Cosmology, Albert Einstein and the Frontiers of Physics, A Theory for Everything, In the Himalayas,* and *Dawning of the Raj*. He has held visiting appointments at The Rockefeller University, The University of Islamabad, The Ecolé Polytechnique, CERN laboratory, Princeton University, and Oxford. This photograph of Jeremy was taken on a bicycle trip in northern California. The thumb, which is on the grounds of the Clos Pegase art gallery and winery in Calistoga, was the work of the French artist Cesar Baldachini. Bernstein has bicycled in many countries including Bali and Crete. He makes his home in New York City and Aspen, Colorado.

Paul M. Fishbane



Paul Fishbane has been teaching undergraduate courses at the University of Virginia, where he is Professor of Physics, for some 25 years. He received his doctoral degree from Princeton University in 1967 and has published some 100 papers in his field, theoretical high energy physics. He is co-author of *Physics for Scientists and Engineers* with Stephen Gasiorowicz and Stephen Thornton. Paul has held visiting appointments at the State University of New York at Stony Brook, Los Alamos Scientific Laboratory, CERN laboratory in Switzerland, Amsterdam's NIKHEF laboratory, France's Institut de Physique Nucleaire, the University of Paris-Sud, and the Ecolé Polytechnique. He has been active for many years at the Aspen Center for Physics, where current issues in physics are discussed with an international group of participants. His other interests include biking, music, and the physics of the kitchen. All of the rest of his time is spent trying to keep up with his family, especially his youngest son Nicholas.

Stephen Gasiorowicz

Stephen Gasiorowicz was born in Poland and received his Ph.D. in physics at the University of California, Los Angeles in 1952. After spending 8 years at the Lawrence Radiation Laboratory in Berkeley, California, he joined the faculty of the University of Minnesota, where his field of research is theoretical high energy physics. As a visiting professor, he has traveled to the Niels Bohr Institute, NORDITA in Copenhagen, the Max Planck Institute for Physics and Astrophysics in Munich, DESY in Hamburg, Fermilab in Batavia, and the Universities of Marseille and Tokyo. He has been a frequent visitor and an officer of the Aspen Center for Physics. Steve is co-author of *Physics for Scientists and Engineers* with Paul Fishbane and Stephen Thornton and has written books on elementary particle physics and quantum physics. A relatively new occupation is that of grandfather, which still leaves some time for reading (history), biking, canoeing, and skiing.

Preface

Knowledge of the revolutions of 20th-century physics is an indispensable part of the training of any engineer and physical scientist. That is because virtually all of today's technology is based, at least in part, on this knowledge. The basic subject material of what is called modern physics is very nearly 100 years old, so that it is hardly modern at at all. Yet just as Newton's laws, today 300 years old, Maxwell's equations, today nearly 150 years old, and the laws of classical statistical physics, more than 100 years old, remain applicable and essential in their respective domains of physical law, so too do the two major developments of the first half of this century: relativity and quantum mechanics. These fundamental subjects underlie a vast scope of application that continues its inventive course today. Moreover, research on fundamental physics has not stopped with relativity and quantum mechanics, and working scientists still face questions as interesting as any that have been answered in the past.

Both relativity and quantum mechanics require the student to make difficult changes in how he or she thinks the physical world works. The subjects violate prejudices that have been built up by everyday experience. For this reason, precision and clarity of explanation are, for us, the first and most important part of the material. We have made every effort to avoid the "it can be shown" approach and to present modern physics in a way that makes its interconnectedness, as well as its connection to classical physics, evident.

Throughout this text, we have built in a historical approach—a discussion of how a subject developed and the thinking that led to its maturation. Often this historical perspective is interwoven with the material; at other times it would interrupt an efficient and compact presentation, and then we present it on the side, as it were. We feel that this approach is useful in that it stresses that the roots of the revolutionary advances lie in experiment; it also makes the text more fun to read.

The book forms the basis of a traditional course in the subject. It contains, in a mathematical language that we have deliberately kept at a level we felt students would be comfortable with, descriptions of the laws of quantum mechanics. It describes applications of these fundamental ideas to both technological and scientific issues. Finally, it describes the subject matter that is of fundamental interest today. All this material is too much to cover in one semester, the usual length of time for such courses, so a more detailed explanation of what we do is in order. This will allow the instructor to make a reasonable choice of what to cover and provide guidance to the reader for the use of the material in the book.

We have broken the material into two parts, even if the boundary between the coverage of the different parts is not always perfectly sharp. The first chapter replaces what would otherwise be a steady set of footnotes referring the reader to an introductory calculus-based textbook.[1] In other words, Chapter 1 is a place to remind students of things that, ideally, they should have fully absorbed in their introductory courses. While the chapter cannot replace such a textbook, it can be a convenient road map to the introductory material. It also constitutes a type of formulary of classical physics. But we urge the student to keep his or her introductory text and to consult it when necessary. The chapter contains no examples or problems, and it is not meant to be assigned as normal course material.

Part 1 is a treatment of the fundamental laws of quantum mechanics. This is a subject with a

[1] For example, see Fishbane, Gasiorowicz, and Thornton, *Physics for Scientists and Engineers*, 2d ed. (Englewood Cliffs, Prentice Hall, 1996).

fascinating yet complex history, but we feel that the number of missteps in the development of quantum mechanics speak against a full historical interweaving of the material with the rest of the text. Thus a separate historical introduction is presented. Chapter 2 describes the experimental data that could not be encompassed by classical physics and examines the daring ideas that opened the gateway to the development of quantum mechanics. Bohr's approach to the structure of the hydrogen atom provided the critical breakthrough, and it merits a chapter on its own, Chapter 3 Extended to circular orbits for other central forces, that approach leads to the quantum nature of rotational and vibrational motion, and it also provides a useful tool for the dependence of energy levels on the relevant physical parameters.

Chapter 4 introduces the Schrödinger equation. Here the problem is to find a way to present this material without getting too heavily into mathematics. One common approach is via wave packets, but they are something with which many students using this text may feel uncomfortable. Instead, we motivate the Schrödinger equation by using classical parallels and the physical meaning of a wave function to argue the form of the Schrödinger equation. This involves bringing in the probability interpretation of the wave function in what we feel is its proper place: right at the beginning. We have kept the mathematics involved in actually solving the Schrödinger equation low, treating just the infinite well here. Only in Chapter 5 do we go into the addition of plane waves with easily managed distributions to get at the concepts of wave packets and of probabilities for measurements of momentum. In that way we can understand the particlelike behavior of a superposition of waves. This material also allows us to introduce the uncertainty relations. We show how they "shield" quantum mechanics from contradictions, and we illustrate their utility in making estimates of ground-state energies.

Starting with Chapter 6 we are in position to see what the Schrödinger equation has to say about some interesting potentials, namely barriers and wells. A good deal of useful physics about scattering and bound states can be conveyed for these mathematically simple situations. We pay particular attention to the physics of tunneling, relating it to internal reflection and to a demonstration that can actually be done in class and describing where it is relevant to physical phenomena. Chapter 7 is a discussion of the Schrödinger equation in the context of the coulomb potential. It is in this chapter that we treat angular momenta, even if we do not employ much in the way of mathematical rigor, and our discussion of the hydrogen atom is concentrated in this chapter, along with the Zeeman effect and the concept of spin. In Chapter 8 we conclude our discussion of the principles of quantum mechanics with the treatment of many-body systems and the symmetry of the wave function for identical particles. This subject is indispensable for an understanding of solids and other material systems, and by putting the exclusion principle here we are prepared for its applications in many domains.

Part 2 of the book is labeled "applications," and it contains discussions of those areas, both in nature and in technology, that cannot be understood without quantum mechanics. The instructor can easily pick and choose among the chapters in this part of the text if he or she is pressed for time. Still, one needs to be aware that there are constraints in some cases; for example, it would be difficult to teach the physics of semiconductors without having first seen the Fermi–Dirac distribution.

Part 2 begins (in Chapter 9) with a discussion of complex atoms and of molecules. We are primarily interested in the quantum mechanical basis of the periodic table, in the way that minima in energy are associated with the mechanisms by which atoms can form molecules, and in simple molecular spectra. The next chapter is a treatment of thermal systems, and because some of the students who take this course may not have had a good background in that material we begin with a simple treatment of classical statistical mechanics, an extremely useful subject for any future engineer or scientist. A treatment of specific heats allows us to understand why one needs a discussion of statistical quantum mechanics. The Boltzmann distribution, a major target, is not only extremely important on its own, it also provides a guide for the development of the quantum mechanical distributions for identical particles. In each case, very simple arguments based on the idea of thermal equilibrium are used. We can also make the connection back to the blackbody distribution first described in Chapter 2, closing a circle.

In Chapter 11 we describe how one can think about unstable systems in quantum mechanics, a topic relevant to atoms in excited states and, by extension, to lasers, whose operation and use form a major part of the chapter. Chapter 12 describes applications to the solid state, a topic so large that we have been forced to make some restrictive choices. We have tried in part to choose according to topics of the greatest current interest to engineers. Accordingly, we have begun with a treatment of how electricity is conducted in materials. When this is coupled with the essential description of band structure, we are led in a natural way to the behavior of semiconductors, a subject with exceptionally rich, diverse applications. We nevertheless restrict ourselves to the more comprehensible topics, leaving out a detailed treatment of many of the more complicated ones—the many varieties of transistors, for example. We also take the opportunity to describe what we think are the most interesting and physically significant aspects of superconductivity. The last chapter in this part, Chapter 13, contains a selection of topics in nuclear physics. The subject is a complex one, and we have chosen on the basis of what we think will illuminate best its various facets; the applications that we examine are equally diverse.

Chapter 14, on particle physics, addresses the unanswered questions of just what are the underlying laws that govern all the other aspects of matter we have described in this book. It is a highly qualitative and descriptive chapter, but it is also a modern one, concentrating on those issues that are actively addressed today.

We would like to offer thanks for the considerable help we were given in the process of writing this book. In addition to the many scientific colleagues who clarified issues we did not understand well enough, we want to thank our editor Alison Reeves, our developmental editor David Chelton, and our production editor Joanne Hakim. Many others at Prentice Hall have helped us, too. In particular, we want to thank Yvonne Gerin and Ray Mullaney. We would also like to acknowledge the following reviewers, who provided valuable feedback.

Albert Altman
University of Massachusetts, Lowell

David Curott
University of North Alabama

Luther Frommhold
University of Texas, Austin

Richard T. Hammond
North Dakota State University

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contains electronic exercies and animations by Wolfgang Christian and Daniel Boye, entitled PHYSLET EXERCISES. The updates and corrections may be found at the site

http: / / www.tpi.umn.edu / ~gasior / modphys.html

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