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Discrete Mathematics with Combinatorics (Second Edition)

离散数学和组合数学

（第2版）

□ James A. Anderson 原著
□ 俞正光 陆 玫 改编

高等教育出版社
Higher Education Press

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清华大学

高等教育出版社
Higher Education Press

图字：01－2005－2300号

图书在版编目（CIP）数据

离散数学和组合数学 = Discrete Mathematics with Combinatorics：第2版，改编版/（美）安德森（Anderson, J. A.）原著；俞正光，陆玫改编. —北京：高等教育出版社，2005.7
（理科类系列教材）
ISBN 7－04－016732－8

Ⅰ.离… Ⅱ.①安…②俞…③陆… Ⅲ.①离散数学－高等学校－教材－英文②组合数学－高等学校－教材－英文 Ⅳ.015

中国版本图书馆 CIP 数据核字（2005）第067627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	889×1194　1/16	**版　　次**	2005年7月第1版
印　　张	39.5	**印　　次**	2005年7月第1次印刷
字　　数	750 000	**定　　价**	41.10元

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物料号　16732－00

SYMBOLS

■ LOGIC

1.	$p \wedge q$	p and q　p 与 q
2.	$p \vee q$	p or q　p 或 q
3.	$\sim p$	not p　非 p
4.	$\veebar$	exclusive or　异或
5.	$p \rightarrow q$	if p then q　若 p 则 q
6.	$p \leftrightarrow q$	p if and only if q　p 当且仅当 q
7.	$p \equiv q$	p is logically equivalent to q　p 与 q 等值
8.	$\mathbf{T}$	statement that is a tautology　永真式
9.	$\mathbf{F}$	statement that is logically false　矛盾式
10.	$\therefore$	therefore　所以
11.	$\mid$	Sheffer stroke (nand)　与非
12.	$\downarrow$	Pierce's arrow (nor)　或非
13.	$\forall$	for all　任意的
14.	$\exists$	There exists　存在

■ SETS

15.	$\{a_1, a_2, a_3, \ldots, a_n\}$	set containing $a_1, a_2, a_3, \ldots, a_n$ 由 $a_1, a_2, a_3, \ldots, a_n$ 组成的集合
16.	$\{x : P\}$	set containing all elements having property P 由所有具有性质 P 的元素组成的集合
17.	$a \in A$	a is an element of the set A　a 属于 A
18.	$A \subseteq B$	the set A is a subset of the set B　A 包含于 B
19.	$\varnothing$	empty set or null set　空集
20.	$\boldsymbol{U}$	universal set　全集
21.	$A \cap B$	intersection of sets A and B　A 交 B
22.	$A \cup B$	union of sets A and B　A 并 B
23.	$A - B$	set difference of sets A and B　A 减 B
24.	$A \triangle B$	symmetric difference of sets A and B　A 与 B 的对称差
25.	A'	complement of the set A　A 的补集
26.	$\mathcal{P}(A)$	power set of the set A　A 的幂集
27.	$A \times B$	cartesian product of sets A and B A 与 B 的笛卡儿积
28.	(a, b)	ordered pair　有序对
29.	$a\,R\,b$	a is related to b by the relation R　a 与 b 有关系 R
30.	R^{-1}	inverse relation of R　R 的逆关系
31.	$S \circ R$	composition of relations S and R　S 与 R 的合成
32.	$(S, \leq)$	partially ordered set with ordering $\leq$　偏序集

■ FUNCTION

33.	$f : A \to B$	function f from A to B　A 到 B 的函数 f
34.	$f(E)$	image of E　E 的像
35.	$f^{-1}(F)$	preimage of F　F 的原像
36.	$f \circ g$	composition of f and g　f 与 g 的合成
37.	f^{-1}	inverse function　逆函数
38.	$f(x) = \lfloor x \rfloor$	floor function　取整函数
39.	$f(x) = \lceil x \rceil$	ceiling function　最高限度函数
40.	$f(x) = x!$	factorial function　阶乘函数

■ GRAPHS AND TREES

41.	$G(V, E)$	graph with vertices V and edges E 由点集 V 和边集 E 组成的图
42.	$\{a, b\}$	edge connecting vertices a and b 连接点 a 和点 b 的边
43.	(a, b)	directed edge from vertex a to vertex b 由 a 指向 b 的边
44.	$deg(v)$	degree of a vertex v　点 v 的度
45.	K_n	complete graph with n vertices　n 个点的完全图
46.	$K_{m,n}$	complete bipartite graph with m and n vertices 完全二部图
47.	$v_0 v_1 v_2 \cdots v_n$	path of length n from v_0 to v_n　v_0 到 v_n 的路
48.	$G^c(V, E')$	complement of graph $G(V, E)$　G 的补图
49.	$C_G(\lambda)$	number of ways of coloring graph $G(V, E)$ using λ colors λ 种颜色对图 G 着色的方法数
50.	$G_{\hat{e}}$	graph G with edge e removed　图 G 中删除边 e
51.	$G_{/e}$	graph G with edge $e = \{a, b\}$ removed and vertices a and b identified 图 G 中收缩边 e
52.	$cl(G)$	closure of graph $G(V, E)$　G 的闭包
53.	$c(e)$	capacity of an edge e　边的容量
54.	$f(e)$	flow in an edge e　边的流量
55.	$val(f)$	value of a flow f　流 f 的值
56.	(S, T)	cut of a network into S and T　割
57.	$C(S, T)$	capacity of a cut (S, T)　割的容量

■ NUMBER THEORY

58.	Z	set of integers　整数集
59.	N or Z^+	set of positive integers　正整数集
60.	$a \equiv b \pmod{n}$	a congruent to b modulo n　a、b 模 n 同余
61.	$[a]$	equivalence class containing a　由 a 生成的等价类
62.	$[a] \oplus [b]$	addition of congruence classes　同余类相加
63.	$[a] \odot [b]$	multiplication of congruence classes　同余类相乘

64. $[[m]]_n$ smallest positve integer congruent to m modulo n
模 n 中同余于 m 的最小正整数

■ RECURSION AND COUNTING

65. $n!$ n factorial n 阶乘
66. $\sum_{i=1}^{n} a_i = a_1 + a_2 + \cdots + a_n$ summation notation 求和记号
67. $P(n,r) = \frac{n!}{(n-r)!}$ number of r permutations on n objects 排列数
68. $C(n,r) = \binom{n}{r} = \frac{n!}{r!(n-r)!}$ number of r combinations on n objects 组合数
69. $C(n : n_1, n_2, \ldots, n_k) = \frac{n!}{n_1!n_2!\ldots n_k!}$ generalized combination 广义组合数
70. $R(p,q)$ Ramsey number Ramsey 数
71. $\mathrm{Fib}(n)$ nth Fibonacci number 第 n 个 Fibonacci 数
72. $\mathrm{Cat}(n) = C_n$ nth Catalan number 第 n 个 Catalan 数
73. $\Delta^k f(x)$ kth difference of $f(x)$ 第 k 次差分
74. E operator defined by $E(f(x) = f(x+1)$
定义为 $E(f(x)) = f(x+1)$ 的算子
75. $x^{(n)}$ $x(x-1)(x-2)\cdots(x-n+1)$
76. $a_n x^{(n)} + a_{n-1}x^{(n-1)} + \cdots + a_2 x^{(2)} + a_1 x + a_0$ factorial polynomial 阶乘多项式
77. $x^{(-m)}$ $\dfrac{1}{(x+m)^m}$
78. $\binom{x}{n}$ $\dfrac{x^{(n)}}{n!}$
79. $s_k^{(n)}$ Stirling number of the first kind 第一类 Stirling 数
80. $S_k^{(n)}$ Stirling number of the second kind 第二类 Stirling 数
81. $\sum$ summation operator 求和算子
82. L_n nth lucas number 第 n 个 Lucas 数
83. D_n the number of derangements of n distinct ordered symbols 错位数
84. $r_k(c)$ the number of ways of placing k rooks on board C in nonattacking position
k 枚不能互相吃掉的车放在棋盘 C 上的方法种数
85. $R(x,C)$ rook polynomial on board C 棋盘 C 上的车多项式
86. $T_k^{(n)}$ the number of ways of placing n distinguishable objects in k distinguishable boxes with no box empty
n 个不同的物品放入 k 个不同的盒子，每盒不同的放法数

■ ALGEBRA

87. $(A, \vee)$ or $(A, +)$ upper semilattice A 上半格
88. $(A, \wedge)$ or $(A, \cdot)$ lower semilattice A 下半格
89. $(S, \vee, \wedge)$ lattice S 格
90. $a \circ H$ left coset 左陪集
91. $\langle a \rangle$ principal ideal generated by a 由 a 生成的主理想
92. $A[x]$ set of polynomials with coefficients in A 多项式集

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封面设计　王凌波

责任印制　陈伟光

出版者的话

为适应当前我国高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，我社开始有计划、大规模地开展了海外优秀理科系列教材的影印及改编工作。海外优秀教材在立体化配套、多种教学资源的整合以及为课程提供整体教学解决方案等方面对我们有不少可资借鉴之处。但一个不容忽视的问题是，外版教材与我国现行的教学内容、教学体系、教学模式和习惯等存在着巨大的差异。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；而国内的情况则不尽相同。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增删，而是结合国内教学特点，引进国外先进的教学思想，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。

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，提交引进版权总数达 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众多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，活跃在教学第一线。他们能够承担此任，不单是因为他们了解引进版教材的知识结构、表达方式和写作方法，更重要的是他们有精力、有热情，愿意付出，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谢意。

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、培训工作，及时地将本套丛书推荐给高校使用。在使用过程中，我们衷心希望广大高校教师和同学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。

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高等教育出版社

2005 年 5 月

In Memory of
Elwood W. Stone and Orville H. Wiebe

To My Family
Marilyn, Andy, Kristin, and Phil
and to
Tom Head, Naoki Kimura,
Leonard S. Laws, and Edward Lee Dubowsky,
Teachers, mentors, and friends

PREFACE

As in the first edition, the purpose of this book is to present an extensive range and depth of topics in discrete mathematics and also work in a theme on how to do proofs. Proofs are introduced in the first chapter and continue throughout the book. Most students taking discrete mathematics are mathematics and computer science majors. Although the necessity of learning to do proofs is obvious for mathematics majors, it is also critical for computer science students to think logically. Essentially, a logical bug-free computer program is equivalent to a logical proof. Also, it is assumed in this book that it is easier to use (or at least not misuse) an application if one understands why it works. With few exceptions, the book is self-contained. Concepts are developed mathematically before they are seen in an applied context.

Additions and alterations in the second edition:

- More coverage of proofs, especially in Chapter 1.
- Added computer science applications, such as a greedy algorithm for coloring the nodes of a graph, a recursive algorithm for counting the number of nodes on a binary search tree, or an efficient algorithm for computing $a^b \bmod n$ for very large values of a, b, and n.
- An extensive increase in the number of problems in the first seven chapters.
- More problems are included that involve proofs.
- Additional material is included on matrices.
- True-False questions at the end of each chapter.
- Summary questions at the end of each chapter.
- Functions and sequences are introduced earlier (in Chapter 2).

Calculus is not required for any of the material in this book. College algebra is adequate for the basic chapters. However, although this book is self-contained, some of the remaining chapters require more mathematical maturity than do the basic chapters, so calculus is recommended more for giving maturity, than for any direct uses.

This book is intended for either a one- or two-term course in discrete mathematics. The first eight chapters of this book provide a foundation in discrete mathematics and would be appropriate for a first-level course for freshmen or sophomores. These chapters are essentially independent, so that the instructor can pick the material he/she wishes to cover. The remainder of the book contains appropriate material for a second course in discrete mathematics. These chapters expand concepts introduced earlier and introduce numerous advanced topics. Topics are explored from different points of view to show how they may be used in different settings. The range of topics include:

Logic - Including truth tables, propositional logic, predicate calculus, circuits, induction, and proofs.

Set Theory - Including cardinality of sets, relations, partially ordered sets, congruence relations, graphs, directed graphs, and functions.

Algorithms - Including complexity of algorithms, search and sort algorithms, the Euclidean algorithm, Huffman's algorithm, Prim's algorithms, Warshall's algorithm, the Ford-Fulkerson algorithm, the Floyd-Warshall algorithm, and Dijkstra's algorithms.

Graph Theory-Including directed graphs, Euler cycles and paths, Hamiltonian cycles and paths, planar graphs, and weighted graphs.

Trees-including binary search trees, weighted trees, tree transversal, Huffman's codes, and spanning trees.

Combinatorics-including permutations, combinations, inclusion-exclusion, partitions, generating functions, Catalan numbers, Sterling numbers, Rook Polynomials, derangements, and enumeration of colors.

Algebra-Including semigroups, groups, lattices, semilattices, Boolean algebras, rings, fields, integral domains, and polynomials.

There is extensive number theory and algebra in this book. I feel that this is a strength of this book, but realize that others may not want to cover these subjects. The chapters in these areas are completely independent of the remainder of the book and can be covered, or not, as the instructor desires. This book also contains finite differences, and other topics not usually found in a discrete mathematics text.

■ Organization

The first three chapters cover logic and set theory. It is assumed in this book that an understanding of proofs is necessary for the logical construction of advanced computer programs.

The basic concepts of a proof are given and illustrated with numerous examples. In Chapter 2, the student is given the opportunity to prove some elementary concepts of set theory. In Chapter 3, the concept of an axiom system for number theory is introduced. The student is given the opportunity to prove theorems in a familiar environment. Throughout the remainder of the book, many proofs are presented and many of the problems are devoted to proofs. Problems, including proofs, begin at the elementary level and advance in level of difficulty throughout the book.

Relations, functions, and graphs are introduced in Chapter 2. Functions are then continued in Chapter 4. However, the development of functions in Chapter 4 is independent of the material in Chapter 2. Similarly, the development of graphs in Chapter 6 does not depend on their development as relations in Chapter 2.

Permutations, and sequences are introduced in Chapter 4 as special types of functions. Algorithms for matrices are introduced and further properties of matrices are developed, which will be used in later chapters on algebra, and counting.

Permutations are used for counting in Chapter 7 and also for applications in algebra and combinatorics in later chapters. Again, the material in Chapter 7, while related to Chapter 4, can be studied independently.

Chapter 5 is independent of the previous chapters except for the matrices in the previous chapter. Algorithms are developed. The complexity of algorithms is also developed in this chapter.

Many elementary concepts of graphs, directed graphs, and trees are covered in Chapter 6. These concepts are covered in more depth in Chapters 12-14. Chapter 6 is independent of the previous chapters.

Chapter 7 is the beginning of extensive coverage of combinatorics. This is continued in many of the chapters including Chapters 10 and 11.

Chapters 8 and 16 cover the basic concepts of algebra, including semigroups, groups, semilattices, lattices, rings, integral domains, and fields. These chapters use Sections 3.4, and 4.2 for examples of groups and rings. Chapter 8 is necessary for the applications in Chapters 15-16.

In many ways Chapters 9, 10, and 11 form a cluster. Recursion is continued in Chapter 9. In addition to the standard linear recurrence relations normally covered in a discrete mathematics text, the theory of finite difference is also covered. Chapter 6 should be covered before this chapter unless the student already has some knowledge of recursion. Chapter 10 continues the counting introduced in Chapter 7. It covers topics introduced in Chapter 7, such as occupancy problems and inclusion-exclusion. It also introduces derangements and rook polynomials. It is closely related to Chapter 9. Many of the same topics are covered from different points of view. One example of this is Stirling numbers. However neither chapter is dependent on the other.

Chapters 9 and 10 are tied together in Chapter 11, where generating functions are used to continue the material in both chapters. In particular, generating functions provide a powerful tool for the solution of occupancy problems.

Chapters 12-14 continue the study of trees and graphs begun in Chapter 6. They obviously depend on the material in Chapter 6, but are virtually independent of most of the preceding chapters. Many of the standard topics of graphs and trees are covered, including planar graphs, Hamiltonian cycles, binary trees, spanning trees, minimal spanning trees, weighted trees, shortest path algorithms, and network flows.

In Chapter 15, algebra and combinatorices are combined for the development of Burnside's Theorem and Polya's Theorem for the enumeration of colors. It primarily depends on a knowledge of permutations found in Section 8.4.

When teaching a beginning course, I normally cover Chapters 1-5 in their entirety, Sections 7.1-7.4, and the first three sections Chapter 6. As mentioned previously, the material in the first seven chapters is arranged for maximal flexibility. The following chart shows the required prerequisites for each chapter.

Chapter	Prequisite Chapters or Sections
Chapter 1	None
Chapter 2	None
Chapter 3	Sections 1.1-1.4 and 2.1
Chapter 4	None
Chapter 5	Sections 4.1-4.2
Chapter 6	None
Chapter 7	None
Chapter 8	Sections 2.6, 2.7, and 3.4
Chapter 9	Sections 5.1-5.3
Chapter 10	Chapter 7
Chapter 11	Chapters 9 and 10
Chapter 12	Chapter 6
Chapter 13	Chapter 6
Chapter 15	Chapter 8
Chapter 16	Chapter 8

■ Supplements

A solutions manual is available from the publisher with complete solutions to all problems. A website is available at www.prenhall.com/janderson. This website includes links to other interesting sites in discrete mathematics, quizzes, and supplementary problems. In addition, there are two problems oriented paperbacks that can be used with the textbook: Practice Problems in Discrete Mathematics (407 pp.) by B. Obrenic and Discrete Mathematics Workbook (316 pp.) by J. Bush. The first consists entirely

of problems with answers/solutions. The second contains an outline of subject, sample worked out problems, and problem sets (with answers). Each of these two supplements is free when shrinkwrapped with the text. As stand-alone items, they have prices. So the order ISBN for the textbook plus the free Obrenic supplement is 013-117279-4. The order ISBN for the textbook plus the free Bush supplement is 013-117278-6.

■ Acknowledgments

First, I would like to thank Dale Saylor for the tremendous amount of work he has contributed to the book. Without him, this book would probably not have been revised. I also want to especially thank Jerome Lewis for the computer science applications which he has contributed to the took. I am very grateful to Douglas Shier for the use of his collection of methods for counting spanning trees. I would like to thank Kristin and Philip Muzik for their excellent artwork. I am especially grateful to James Bell for the tremendous amount of work that he contributed to the first edition. I would also like to thank my colleagues Rick Chow, Dale Saylor, Debabrata Mukherjee, and Jerome Lewis for their help in checking answers to the exercises. I would like to thank Alex Osipovk, Ole-Kristian S. Losvik, Timothy Haven, and others who have sent me corrections to the first edition of the book. I would also like to thank George Lobell and Jennifer Brady at Prentice Hall and Bob Walters of Prepress Management, Inc., for their help with the book.

With apologies for the delay, I would like to thank the following reviewers of the first edition:

Anthony B. Evans, Wright State University
Madeleine Schep, Columbia College
Akihiro Kanamori, Boston University
Krishnaiya Thulasiraman, University of Oklahoma
Gabor Sarkozy, Worcester Polytechnic Institute
Alvin Swimmer, Arizona State University

I would also like to thank the following reviews of this edition:

Beth Novick, Clemson University
Thomas Hughes, Vanier College/Concordia University
John Konvalina, University of Nebraska-Omaha
George M. Butler, Louisiana Tech University
Michael Neubauer, California State University, Northridge
Myron Hlynka, University of Windsor
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