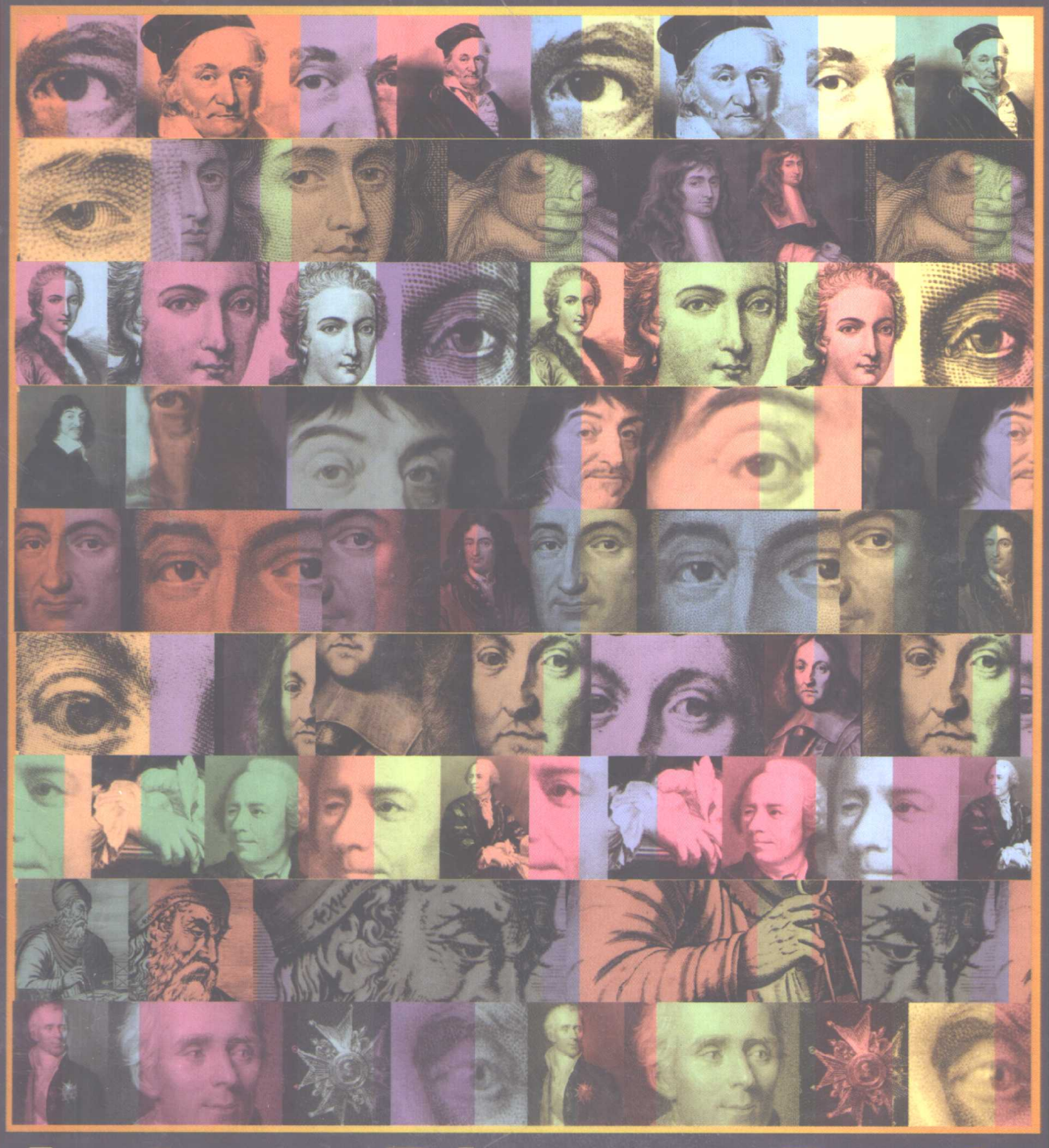
Seventh Edition

Calculus



Anton · Bivens · Davis

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Calculus

SEVENTH EDITION

HOWARD ANTON
Drexel University

IRL BIVENS
Davidson College

STEPHEN DAVIS
Davidson College

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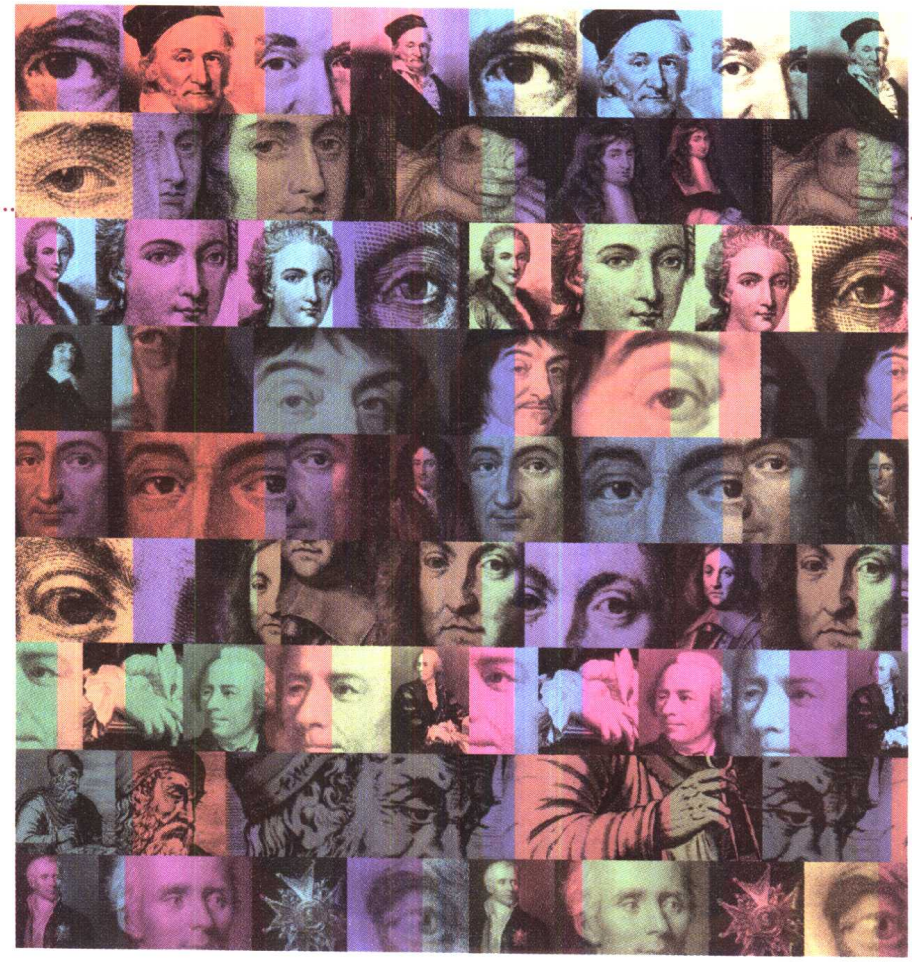

Calculus

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To
My Wife Pat
My Children: Brian, David, and Lauren

In Memory of
My Mother Shirley
My Father Benjamin
My Esteemed Colleague Albert Herr
My Benefactor Stephen Girard (1750–1831)

HA

To
My Son Robert

IB

To
My Wife Elisabeth
My Children: Laura, Anne, and James

SD

About Howard Anton

Howard Anton obtained his B.A. from Lehigh University, his M.A. from the University of Illinois, and his Ph.D. from the Polytechnic University of Brooklyn, all in mathematics. In the early 1960s he worked for Burroughs Corporation and Avco Corporation at Cape Canaveral, Florida, where he was involved with the manned space program. In 1968 he joined the Mathematics Department at Drexel University, where he taught full time until 1983. Since that time he has been an adjunct professor at Drexel and has devoted the majority of his time to textbook writing and activities for mathematical associations. Dr. Anton was president of the EPADEL Section of the Mathematical Association of America (MAA), served on the board of Governors of that organization, and guided the creation of the Student Chapters of the MAA. He has published numerous research papers in functional analysis, approximation theory, and topology, as well as pedagogical papers. He is best known for his textbooks in mathematics, which are among the most widely used in the world. There are currently more than one hundred versions of his books, including translations into Spanish, Arabic, Portuguese, Italian, Indonesian, French, Japanese, Chinese, Hebrew, and German. For relaxation, Dr. Anton enjoys traveling and photography.

About Irl Bivens

Irl C. Bivens, recipient of the George Polya Award and the Merten M. Hasse Prize for Expository Writing in Mathematics, received his A.B. from Pfeiffer College and his Ph.D. from the University of North Carolina at Chapel Hill, both in mathematics. Since 1982, he has taught at Davidson College, where he currently holds the position of professor of mathematics. A typical academic year sees him teaching courses in calculus, topology, and geometry. Dr. Bivens also enjoys mathematical history, and his annual History of Mathematics seminar is a perennial favorite with Davidson mathematics majors. He has published numerous articles on undergraduate mathematics, as well as research papers in his specialty, differential geometry. He is currently a member of the editorial board of the new MAA Problem Book series, a reviewer for *Mathematical Reviews*, associate editor of the *College Mathematics Journal*, and a coeditor of the Problems and Solutions section of the *College Mathematics Journal*. When he is not pursuing mathematics, Professor Bivens can be found perfecting his juggling technique or catching an action flick with his son Robert. He and Howard Anton met in 1987 on a mathematical lecture tour of the People's Republic of China.

About Stephen Davis

Stephen L. Davis received his B.A. from Lindenwood College and his Ph.D. from Rutgers University in mathematics. Having previously taught at Rutgers University and Ohio State University, Dr. Davis came to Davidson College in 1981, where he is currently a professor of mathematics and chair of the Department of Mathematics. He regularly teaches calculus, linear algebra, abstract algebra, and computer science. A sabbatical in 1995–1996 took him to Swarthmore College as a visiting associate professor. Professor Davis has published numerous articles on calculus reform and testing, as well as research papers on finite group theory, his specialty. Professor Davis is currently secretary-treasurer of the Southeastern Section of the Mathematics Association of America, a faculty consultant for the Educational Testing Service Advanced Placement Calculus Test, a board member of the North Carolina Association of Advanced Placement Mathematics Teachers, and is actively involved in nurturing mathematically talented high school students through leadership in the Charlotte Mathematics Club. He was formerly North Carolina state director for the MAA. For relaxation, he plays basketball, juggles, and travels. Professor Davis and his wife Elisabeth have three children, Laura, Anne, and James, all former calculus students.

PREFACE

ABOUT THIS EDITION

The primary goal of this edition is to foster ***conceptual understanding*** and an appreciation of the ***applicability*** of the subject matter. Some of the significant features of this edition are as follows:

Multiple Versions For greater flexibility, there are now two versions of this text — *late transcendental* and *early transcendental*. The late transcendental version covers logarithmic, exponential, and inverse trigonometric functions *after* all of the basic material on differentiation and integration has been developed; in the early transcendental version, logarithmic, exponential, and inverse trigonometric functions are discussed earlier. The late transcendental version is organized along the lines of the fifth edition and the early transcendental version along the lines of the sixth edition. Both versions of this text are available in two volumes, a brief edition that covers the single variable material, and a multivariable edition that covers the multivariable material.

Technology This edition provides many examples and exercises for instructors who want to use graphing calculators, computer algebra systems, or other programs. However, these are implemented in a way that allows the text to be used in courses where technology is used extensively, moderately, or not at all. To provide a sound foundation for the technology material, we have included a section entitled Graphing Functions on Calculators and Computers; Computer Algebra Systems (Section 1.3). The text is accompanied by a CD containing the program *Graphing Advantage Plus*, which is a Windows program that can be used for graphing, numerical integration, finding roots and intersections, and curve fitting by least squares.

Horizon Modules Selected chapters end with modules called *Expanding the Calculus Horizon*. As the name implies, these modules are intended to take the student a step beyond the traditional calculus text. The modules, all of which are optional, can be assigned either as individual or group projects and can be used by instructors to tailor the calculus course to meet their specific needs and teaching philosophies. For example, there are modules that touch on iteration and dynamical systems, equations of motion, application of integration to railroad design, collision of comets with Earth, and hurricane modeling.

Mathematical Modeling Mathematical modeling plays a prominent role in this edition. A new section on mathematical modeling has been added early in the text (Section 1.7). In Sections 9.3 and 9.4 we discuss mathematical modeling with differential equations, in Section 10.10 we discuss mathematical modeling with Taylor series, and in Chapter 16 we present a Horizon module that develops a mathematical model of a hurricane.

Applicability of Calculus One of the primary goals of this edition is to link calculus to the real world and the student's own experience. This theme starts with the Introduction and is carried through in the examples, exercises, and modules. Applications given in the exercises have been chosen to provide the student a sense of how calculus can be applied.

Early Differential Equations Basic ideas about differential equations, initial-value problems, direction fields, and integral curves are introduced concurrently with integration and then revisited in more detail in Chapter 9. We have also added new material on second-order differential equations.

For the Reader At various points in the exposition the student is assigned a brief task. Some of these are appropriate for all readers, and others are appropriate only for readers who have a graphing utility or a CAS. The tasks for all readers are designed to immerse students more deeply into the text by asking them to think about an idea and reach some conclusion; the tasks for students using technology are designed to familiarize them with the procedures for using that technology by asking them to read their documentation and perform some text-related computation. Some instructors may want to make these tasks part of their assignments.

Logarithmic and Exponential Functions Logarithmic and exponential functions are introduced in Section 7.2 from the exponent point of view and then revisited from the integral point of view in Section 7.5. The organization has been designed so that instructors who want to deemphasize the integral definition can do so without compromising the integrity of the material.

Early Parametric Option In keeping with the current trend of discussing parametric equations early, parametric curves are introduced in Section 1.8 and then revisited in Chapter 11, where calculus-related matters are discussed. Instructors who prefer the traditional late discussion of parametric equations will have no problem deferring the material in Section 1.8 until the discussion of analytic geometry in Chapter 11.

More Variety in Exercises The exercise sets have been revised and expanded to include more variety and better pairings between odd and even exercises. There are many more exercises on mathematical modeling and the use of technology. As in earlier editions, a large number of exercises focus on *conceptual understanding*. Exercises that require technology are marked with icons for easy identification. Supplementary exercises at the ends of the chapters draw on all of the concepts developed in the chapter.

Analysis of Functions The traditional "curve sketching" is part of the *Analysis of Functions* (Sections 4.1–4.3). The approach has been updated to focus on the interplay between calculus and technology, with the goal of locating, describing, and analyzing all of the significant features of a graph.

Principles of Integral Evaluation The traditional "Techniques of Integration" is now entitled "Principles of Integral Evaluation" to reflect its more modern approach to the material. The chapter emphasizes general methods and the role of technology rather than specific tricks for evaluating complicated or obscure integrals.

Appendix on Polynomial Equations Since many calculus students are weak in solving polynomial equations, we have included an appendix (Appendix F) that reviews the Factor Theorem, the Remainder Theorem, and procedures for finding rational roots.

Rule of Four The "rule of four" refers to presenting concepts from the verbal, algebraic, visual, and numerical points of view. In keeping with current pedagogical philosophy, we used this approach whenever appropriate.

Internet This text is supplemented by an Internet site

http://www.wiley.com/college/anton

OTHER FEATURES

Flexibility This edition has a built-in flexibility that is designed to serve a broad spectrum of calculus philosophies—from traditional to reform. Technology can be emphasized or not, and the order of many topics can be permuted freely to accommodate the instructor's specific needs.

Trigonometry Review Deficiencies in trigonometry plague many students, so we have included a substantial trigonometry review in Appendix E.

Historical Notes The biographies and historical notes have been a hallmark of this text from its first edition and have been maintained. All of the biographical materials have been distilled from standard sources with the goal of capturing the personalities of the great mathematicians and bringing them to life for the students.

Graded Exercise Sets Section Exercise Sets are "graded" to begin with routine problems and progress gradually toward problems of greater difficulty. However, the Supplementary Exercises are not graded by level of difficulty, so as not to give the student a predisposition about the level of effort required.

Rigor The challenge of writing a good calculus book is to strike the right balance between rigor and clarity. Our goal is to present precise mathematics to the fullest extent possible for the freshman audience. Where clarity and rigor conflict, we choose clarity; however, we believe it to be important that the student understand the difference between a careful proof and an informal argument, so we have tried to make it clear to the reader when the arguments being presented are informal or motivational. Theory involving ϵ-δ arguments appear in separate sections so that they can be covered or not, as preferred by the instructor.

Mathematical Level This text is written at a mathematical level that will prepare students for a wide variety of careers that require a sound mathematics background, including engineering, the various sciences, and business.

Computer Graphics This edition makes extensive use of modern computer graphics to clarify concepts and to develop the student's ability to visualize mathematical objects, particularly those in 3-space. For those students who are working with graphing technology, there are many exercises that are designed to develop the student's ability to generate and analyze mathematical curves and surfaces.

New Features in the Seventh Edition

- There are now both early transcendental and late transcendental versions of this text.
- About one-third of the exercises are new. They provide more exploratory and open-ended problems, more exercises involving tabular data, more exercises that use technology, and better pairing of odd and even exercises.
- There is more emphasis on mathematical modeling. There is a new early introduction to the topic (Section 1.7) and greater emphasis on modeling with differential equations.
- Section 9.4 on second-order differential equations is new.
- Chapter 10 on infinite series has been reorganized to allow instructors to get to the heart of the material more quickly.
- Section 11.5 on rotation of coordinate axes, which had been relegated to the Internet in the sixth edition, has been restored to the text.
- Section 14.4 on differentiability and local linearity for functions of several variables has been rewritten extensively for greater clarity.

A Welcome to My New Coauthors

It is hard to believe that a quarter-century has passed since I first began writing this book in a small office tucked away in a corner of my bedroom. What I naively believed would be a two-year writing project took almost eight years. I have been told by many that this text established a new standard of clarity in mathematical exposition and changed the way in which calculus books are written — of that I am proud. However, after a lifetime working as a lone author, the inexorable passage of time has made it clear to me that the moment for coauthors has arrived — and so I welcome my new writing colleagues, Irl Bivens and Stephen Davis, both of whom have unique talents and years of teaching experience in calculus. They have been a pleasure to work with, and I thank them for their dedication and contributions to this new edition.

Howard Anton

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SUPPLEMENTS FOR THE STUDENT

Student Resource Manual 0471-441708

The *Student Resource Manual* provides students with detailed solutions to odd-numbered exercises from the text, as well as including sample tests for each section and chapter of the text. Available for purchase at www.wiley.com/college

Student Resource and Survival CD 0471-441694

Available for both Windows and Macintosh users, the *Student Resource and Survival CD* contains detailed solutions to odd-numbered exercises from the text and sample tests for each section and chapter of the text. In addition, this CD features precalculus review material and a brief introduction to those aspects of linear algebra which are of immediate concern for the calculus student. Available for purchase at www.wiley.com/college

Graphing Advantage Plus™

This Windows program can be used to solve most of the technology exercises in this text that are labeled with the icon , thereby eliminating the need to purchase a graphing calculator or other program for that purpose. The program also allows the user to export graphs to word processing documents for reports, and to display various kinds of course materials and Internet links in a convenient menu that can be customized. If a CAS is to be used in the course, then the user can create a customized menu that accesses the CAS with a quick click. The *Calculus Resource CD* packaged with this text contains a free time-limited version that will be active for 16 weeks (about a semester). Instructions for obtaining an unrestricted version are included on the CD.

Electronic Calculus Tutorial

This electronic calculus tutorial developed by Intelligent Environments is a software package that solves and documents calculus problems in real time. This intelligent software package steps students through problems and provides customized feedback from the text, allowing students to identify and learn from their mistakes more efficiently. Instructors can use the tutorial to preview problems and explore functions graphically and analytically. For more information, visit www.wiley.com/college/anton or speak with your Wiley representative.

SUPPLEMENTS FOR THE INSTRUCTOR

SUPPLEMENTS FOR THE INSTRUCTOR CAN BE OBTAINED BY SENDING A REQUEST ON YOUR INSTITUTIONAL LETTERHEAD TO MATHEMATICS MARKETING MANAGER, JOHN WILEY & SONS, INC., 605 THIRD AVENUE, NEW YORK, NY 10158-0012, OR BY CONTACTING YOUR LOCAL WILEY REPRESENTATIVE.

Complete Solutions Manual

Detailed solutions to all exercises in the text.

Test Bank

Contains a variety of questions and solutions for every section in the text.

Instructor's Resource CD-ROM

Contains the complete *Solutions Manual* and *Test Bank*, as well as precalculus review material and a brief introduction to linear algebra.

Graphing Advantage Plus

A version of *Graphing Advantage Plus* (described above) without time restrictions. The program can be used for classroom presentations, for creating overhead transparencies with colorized graphs, and for exporting graphs to word processing documents for creating examinations.

Other Resources for the Instructor

eGrade

An on-line assessment system that contains a large bank of skill-building problems and solutions. Instructors can now automate the process of assigning, delivering, grading, and routing all kinds of homework, quizzes, and tests while providing students with immediate scoring and feedback on their work. Wiley *eGrade* "does the math"... and much more. For more information, visit www.wiley.com/college/egrade

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The Faculty Resource Network

The *Faculty Resource Network* is a peer-to-peer network of academic faculty dedicated to the effective use of technology in the classroom. This group can help you apply innovative classroom techniques, implement specific software packages, and tailor the technology experience to the specific needs of each individual class. Ask your Wiley representative for more details.

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