CALCULUS 6e

MATRIX VERSION

EDWARDS & PENNEY

CALCULUS

Matrix Version

Sixth Edition

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ABOUT THE AUTHORS

C. Henry Edwards is emeritus professor of mathematics at the University of Georgia. He earned his Ph.D. at the University of Tennessee in 1960, and recently retired after 40 years of classroom teaching (including calculus or differential equations almost every term) at the universities of Tennessee, Wisconsin, and Georgia, with a brief interlude at the Institute for Advanced Study (Princeton) as an Alfred P. Sloan Research Fellow. He has received numerous teaching awards, including the University of Georgia's *honoratus* medal in 1983 (for sustained excellence in honors teaching), its Josiah Meigs award in 1991 (the institution's highest award for teaching), and the 1997 state-wide Georgia Regents award for research university faculty teaching excellence. His scholarly career has ranged from research and dissertation direction in topology to the history of mathematics to computing and technology in the teaching and applications of mathematics. In addition to being author or co-author of calculus, advanced calculus, linear algebra, and differential equations textbooks, he is well-known to calculus instructors as author of *The Historical Development of the Calculus* (Springer-Verlag, 1979). During the 1990s he served as a principal investigator on three NSF-supported projects: (1) A school mathematics project including Maple for beginning algebra students, (2) A Calculus-with-*Mathematica* program, and (3) A MATLAB-based computer lab project for numerical analysis and differential equations students.

David E. Penney, University of Georgia, completed his Ph.D. at Tulane University in 1965 (under the direction of Prof. L. Bruce Treybig) while teaching at the University of New Orleans. Earlier he had worked in experimental biophysics at Tulane University and the Veteran's Administration Hospital in New Orleans under the direction of Robert Dixon McAfee, where Dr. McAfee's research team's primary focus was on the active transport of sodium ions by biological membranes. Penney's primary contribution here was the development of a mathematical model (using simultaneous ordinary differential equations) for the metabolic phenomena regulating such transport, with potential future applications in kidney physiology, management of hypertension, and treatment of congestive heart failure. He also designed and constructed servomechanisms for the accurate monitoring of ion transport, a phenomenon involving the measurement of potentials in microvolts at impedances of millions of megohms. Penney began teaching calculus at Tulane in 1957 and taught that course almost every term with enthusiasm and distinction until his retirement at the end of the last millennium. During his tenure at the University of Georgia he received numerous University-wide teaching awards as well as directing several doctoral dissertations and seven undergraduate research projects. He is the author of research papers in number theory and topology and is the author or co-author of textbooks on calculus, computer programming, differential equations, linear algebra, and liberal arts mathematics.

PREFACE

Contemporary calculus instructors and students face traditional challenges as well as new ones that result from changes in the role and practice of mathematics by scientists and engineers in the world at large. As a consequence, this sixth edition of our calculus textbook is its most extensive revision since the first edition appeared in 1982.

One chapter of the fifth edition has been replaced in the table of contents by two entirely new ones; most of the remaining chapters have been extensively rewritten. Nearly 160 of the book's over 800 worked examples are new for this edition and the 1850 figures in the text include 250 new computer-generated graphics. Almost 800 of its 7250 problems are new, and these are augmented by over 330 new conceptual discussion questions that now precede the problem sets. Moreover, almost 1100 new true/false questions are included in the Study Guides on the new CD-ROM that accompanies this edition. In summary, almost 2200 of these 8650-plus problems and questions are new, and the text discussion and explanations have undergone corresponding alteration and improvement.

PRINCIPAL NEW FEATURES

The current revision of the text features

- More unified treatment of **transcendental functions** in Semester I,
- **Differential equations** and applications in Semester II, and
- **Linear systems and matrices** in Semester III.

The new chapter on differential equations now appears immediately after Chapter 8 on techniques of integration. It includes both direction fields and Euler's method together with the more elementary symbolic methods (which exploit techniques from Chapter 8) and interesting applications of both first- and second-order equations. Chapter 11 (Infinite Series) now ends with a new section on power series solutions of differential equations, thus bringing full circle a unifying focus of second-semester calculus on elementary differential equations.

Linear systems and matrices, ending with an elementary treatment of eigenvalues and eigenvectors, are now introduced in Chapter 12. The subsequent coverage of multivariable calculus now integrates matrix methods and terminology with the traditional notation and approach—including (for instance) introduction and extensive application of the chain rule in matrix-product form.

NEW LEARNING RESOURCES

Conceptual Discussion Questions The set of problems that concludes each section is now preceded by a brief **Concepts: Questions and Discussion** set consisting of several openended conceptual questions that can be used for either individual study or classroom discussion.

The Text CD-ROM The content of the new CD-ROM that accompanies this text is fully integrated with the textbook material, and is designed specifically for use hand-in-hand with study of the book itself. This CD-ROM features the following resources to support learning and teaching:

- **Interactive True/False Study Guides** that reinforce and encourage student reading of the text. Ten author-written questions for each section carefully guide students through the section, and students can request individual hints suggesting where in the section to look for needed information.
- **Live Examples** feature dynamic multimedia and computer algebra presentations—many accompanied by audio explanations—which enhance student intuition and understanding. These interactive examples expand upon many of the textbook's principal examples; students can change input data and conditions and then observe the resulting changes in step-by-step solutions and accompanying graphs and figures. **Walkthrough videos** demonstrate how students can interact with these live examples.
- **Homework Starters** for the principal types of computational problems in each textbook section, featuring both interactive presentations similar to the live examples and (Web-linked) voice-narrated videos of pencil-and-paper investigations illustrating typical initial steps in the solution of selected textbook problems.
- **Computing Project Resources** support most of the over three dozen projects that follow key sections in the text. For each such project marked in the text by a CD-ROM icon, more extended discussions illustrating Maple, *Mathematica,* MATLAB, and graphing calculator investigations are provided. Computer algebra system commands can be copied and pasted for interactive execution.
- **Hyperlinked Maple Worksheets** contributed by Harald Pleym of Telemark University College (Norway) constitute an interactive version of essentially the whole textbook. Students and faculty using Maple can change input data and conditions in most of the text examples to investigate the resulting changes in step-by-step solutions and accompanying graphs and figures.
- **PowerPoint Presentations** provide classroom projection versions of about 350 of the figures in the text that would be least convenient to reproduce on a blackboard.
- **Web Site** The contents of the CD-ROM together with additional learning and teaching resources are maintained and updated at the textbook Web site **www.prenhall.com/edwards,** which includes a Comments and Suggestions center where we invite response from both students and instructors.

PH Grade Assist (Computerized Homework Grading System) About 2000 of the textbook problems are incorporated in an automated grading system that is now available. Each problem solution in the system is structured algorithmically so that students can work in a computer lab setting to submit homework assignments for automatic grading. (There is a small annual fee per participating student.)

New Solutions Manuals The entirely new 1875-page **Instructor's Solutions Manual** (available in three volumes) includes a detailed solution for every problem in the book. These solutions were written exclusively by the authors and have been checked independently by others.

The entirely new 965-page **Student Solutions Manual** (available in two volumes) includes a detailed solution for every odd-numbered problem in the text. The answers (alone) to most of these odd-numbered problems are included in the answers section at the back of this book.

New Technology manuals Each of the following manuals is available shrink-wrapped with any version of the text for half the normal price of the manual (all of

which are inexpensive):

- Jensen, *Using MATLAB in Calculus* (0-13-027268-X)
- Freese/Stegenga, *Calculus Concepts Using Derive* (0-13-085152-3)
- Gresser, *TI Graphing Calculator Approach, 2e* (0-13-092017-7)
- Gresser, *A Mathematica Approach, 2e* (0-13-092015-0)
- Gresser, *A Maple Approach, 2e* (0-13-092014-2)

THE TEXT IN MORE DETAIL . . .

In preparing this edition, we have taken advantage of many valuable comments and suggestions from users of the first five editions. This revision was so pervasive that the individual changes are too numerous to be detailed in a preface, but the following paragraphs summarize those that may be of widest interest.

▼ **New Problems** Most of the almost 800 new problems lie in the intermediate range of difficulty, neither highly theoretical nor computationally routine. Many of them have a new technology flavor, suggesting (if not requiring) the use of technology ranging from a graphing calculator to a computer algebra system.

▼ **Discussion Questions and Study Guides** We hope the 330 conceptual discussion questions and 1080 true/false study-guide questions constitute a useful addition to the traditional fare of student exercises and problems. The True/False Study Guide for each section provides a focus on the key ideas of the section, with the single goal of motivating guided student reading of the section.

▼ **Examples and Explanations** About 20% of the book's worked examples are either new or significantly revised, together with a similar percentage of the text discussion and explanations. Additional computational detail has been inserted in worked examples where students have experienced difficulty, together with additional sentences and paragraphs in similar spots in text discussions.

▼ **Project Material** Many of the text's three dozen projects are new for this edition. These appear following the problem sets at the ends of key sections throughout the text. Most (but not all) of these projects employ some aspect of modern computational technology to illustrate the principal ideas of the preceding section, and many contain additional problems intended for solution with the use of a graphing calculator or computer algebra system. Where appropriate, project discussions are significantly expanded in the CD-ROM versions of the projects.

▼ **Historical Material** Historical and biographical chapter openings offer students a sense of the development of our subject by real human beings. Indeed, our exposition of calculus frequently reflects the historical development of the subject—from ancient times to the ages of Newton and Leibniz and Euler to our own era of new computational power and technology.

TEXT ORGANIZATION

▼ **Introductory Chapters** Instead of a routine review of precalculus topics, Chapter 1 concentrates specifically on functions and graphs for use in mathematical modeling. It includes a section cataloging informally the elementary transcendental functions of calculus, as background to their more formal treatment using calculus itself. Chapter 1 concludes with a section addressing the question "What *is* calculus?" Chapter 2 on limits begins with a section on tangent lines to motivate the official introduction of limits in Section 2.2. Trigonometric limits are treated

throughout Chapter 2 in order to encourage a richer and more visual introduction to the limit concept.

▼ **Differentiation Chapters** The sequence of topics in Chapters 3 and 4 differs a bit from the more traditional order. We attempt to build student confidence by introducing topics more nearly in order of increasing difficulty. The chain rule appears quite early (in Section 3.3) and we cover the basic techniques for differentiating algebraic functions before discussing maxima and minima in Sections 3.5 and 3.6 (in order to illustrate early some significant applications of the derivative). Section 3.7 treats the derivatives of all six trigonometric functions. The authors' fondness for Newton's method (Section 3.8) will be apparent.

The mean value theorem and its applications are deferred to Chapter 4 (following implicit differentiation and related rates in Section 4.1, and differentials and linear approximation in Section 4.2). In addition, a dominant theme of Chapter 4 is the use of calculus both to construct graphs of functions and to explain and interpret graphs that have been constructed by a calculator or computer. This theme is developed in Sections 4.4 on the first derivative test and 4.6 on higher derivatives and concavity.

▼ **Integration Chapters** Chapter 5 begins with a section on antiderivatives—which could logically be included in the preceding chapter, but benefits from the use of integral notation. When the definite integral is introduced in Sections 5.3 and 5.4, we emphasize endpoint and midpoint sums rather than upper and lower and more general Riemann sums. This concrete emphasis carries through the chapter to its final section on numerical integration. Chapter 6 begins with a largely new section on Riemann sum approximations, with new examples centering on fluid flow and medical applications. Section 6.6 is a new treatment of centroids of plane regions and curves.

Chapter 8 (Techniques of Integration) is organized to accommodate those instructors who feel that methods of formal integration now require less emphasis, in view of modern techniques for both numerical and symbolic integration. Integration by parts (Section 8.3) precedes trigonometric integrals (Section 8.4). The method of partial fractions appears in Section 8.5, and trigonometric substitutions and integrals involving quadratic polynomials follow in Sections 8.6 and 8.7. Improper integrals appear in Section 8.8, with new and substantial subsections on special functions and probability and random sampling. This rearrangement of Chapter 8 makes it more convenient to stop wherever the instructor desires.

▼ **Calculus of Transcendental Functions** Section 7.1 (much strengthened for this edition) introduces the exponential and logarithmic functions from a fairly intuitive viewpoint; the approach based on the natural logarithm as an integral appears in Section 7.4. Sections 7.2 and 7.3 introduce l'Hôpital's rule and apply it to round out the calculus of exponential and logarithmic functions. Sections 7.5 and 7.6 cover both derivatives of and integrals involving inverse trigonometric functions and hyperbolic functions.

▼ **Differential Equations** This entirely new chapter begins with the most elementary differential equations and applications (Section 9.1) and then proceeds to introduce both graphical (slope field) and numerical (Euler) methods in Section 9.2. Subsequent sections of the chapter treat separable and linear first-order differential equations and (in more depth than usual in a calculus course) applications such as population growth (including logistic and predator-prey populations) and motion with resistance. The final two sections of Chapter 9 treat second-order linear equations and applications to mechanical vibrations. Instructors desiring still more coverage of differential equations can arrange with the publisher to bundle and use appropriate sections of Edwards and Penney, **Differential Equations: Computing and Modeling 2/e** (Prentice-Hall, 2000).

▼ **Parametric Curves and Polar Coordinates** The principal change in Chapter 10 is the replacement of three separate sections in the 5th edition on parabolas, ellipses, and hyperbolas with a single Section 10.6 that provides a unified treatment of all the conic sections.

▼ **Infinite Series** After the usual introduction to convergence of infinite sequences and series in Sections 11.2 and 11.3, a combined treatment of Taylor polynomials and Taylor series appears in Section 11.4. This makes it possible for the instructor to experiment with a briefer treatment of infinite series, but still offer exposure to the Taylor series that are so important for applications. The principal change in Chapter 11 is the addition of a new final section on power series methods and their use to introduce new transcendental functions, thereby concluding the middle third of the book with a return to differential equations.

▼ **Vectors and Matrices** After covering vectors in its first four sections, Chapter 12 continues with three sections on solution of linear systems (through elementary Gaussian elimination), matrices (through calculation of inverse matrices), and eigenvalues and eigenvectors and their use in classification of rotated conics. This introduction of linear systems and matrices provides the preparation required for the matrix-oriented multivariable calculus of Chapter 14. The intervening Chapter 13 (Curves and Surfaces in Space) includes discussion of Kepler-Newton motion of planets and satellites. The chapter concludes with a brief application of eigenvalues to the discussion of rotated quadric surfaces in space.

▼ **Multivariable Calculus** Appropriately enough, the introduction and initial application of partial derivatives is traditional. But, beginning with the introduction of the multivariable chain rule in matrix-product form, matrix notation and terminology is used consistently in the remainder of Chapter 14. This approach affords a more clear-cut treatment of differentiability and linear approximation of multivariable functions, as well as of directional derivatives and Lagrange multipliers. We conclude Chapter 14 with a classification of critical points based on eigenvalues of the (Hessian) matrix of second derivatives (thereby generalizing directly the second derivative test of single-variable calculus). As a final illustration of the utility of matrix methods, this approach unifies the standard discriminant-based classification of two-variable critical points with the analogous classification of critical points for function of three or more variables. Matrix methods (naturally) are needed less frequently in Chapters 15 (Multiple Integrals) and 16 (Vector Calculus), but appear whenever a change of variables in a multiple integral is involved.

OPTIONS IN TEACHING CALCULUS

The Calculus Sequence The present version of the text is accompanied by one that treats transcendental functions earlier in single-variable calculus and but omits matrices from use in multivariable calculus. Both versions of the complete text are also available in two-volume split editions. By appropriate selection of first and second volumes, the instructor can therefore construct a complete text for a calculus sequence with

- Early transcendentals in single-variable calculus and matrices in multivariable calculus;
- Early transcendentals in single-variable calculus but traditional coverage of multivariable calculus;
- Transcendental functions delayed until after the integral in single-variable calculus, but matrices used in multivariable calculus;
- Neither early transcendentals in single-variable calculus nor matrices in multivariable calculus.

Maximum-Minimum Problems The text includes first coverage of maximum-minimum problems in Chapter 3 (Sections 3.5 and 3.6) to provide early motivation in the form of concrete applications of the derivative, and then returns to them with the first- and second-derivative tests of Sections 4.4 and 4.6. However, some instructors may prefer to treat these applications later—following trigonometric derivatives and related rates, and along with the bulk of the associated material in Chapter 4. The modular character of the pertinent sections in these two differential calculus chapters permits such desired rearrangements of the material within the typical pair of instructional units (each likely followed by its own hour test). For instance, Sections 3.5 and 3.6 on max-min problems can be deferred and used to begin the second unit on differential calculus, after appending Sections 4.1 (Implicit Differentiation and Related Rates) and 4.2 (Increments, Differentials, and Linear Approximation) to the first unit. Thus the material in Chapters 3 and 4 would be covered in the following order.

Unit I: Differentiation

3.1 The Derivative and Rates of Change
3.2 Basic Differentiation Rules
3.3 The Chain Rule
3.4 Derivatives of Algebraic Functions
3.7 Derivatives of Trigonometric Functions (skipping Example 13 and Problems 78–86)
3.8 Successive Approximations and Newton's Method
4.1 Implicit Functions and Related Rates
4.2 Increments, Differentials, and Linear Approximation

Unit II: Applications of the Derivative

3.5 Maxima and Minima of Functions on Closed Intervals
3.6 Applied Optimization Problems
4.3 Increasing and Decreasing Functions and the Mean Value Theorem
4.4 The First Derivative Test and Applications
4.5 Simple Curve Sketching
4.6 Higher Derivatives and Concavity
4.7 Curve Sketching and Asymptotes

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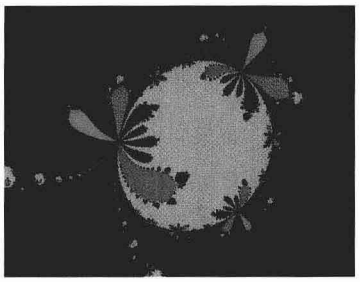

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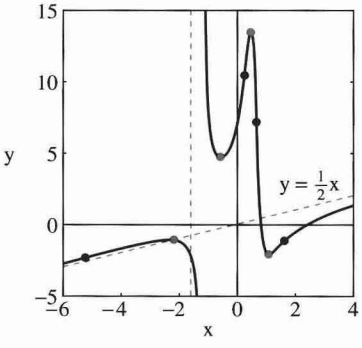

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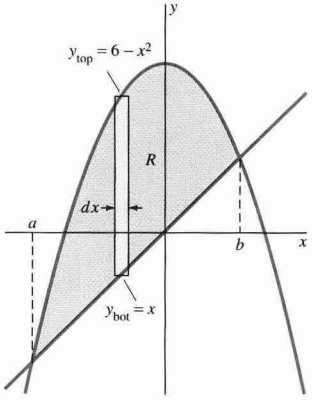

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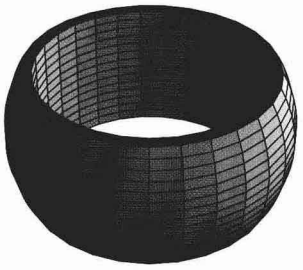

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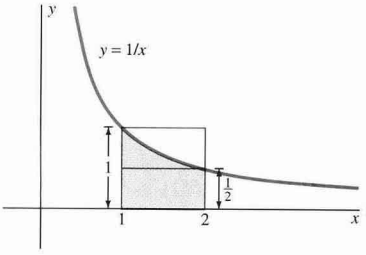

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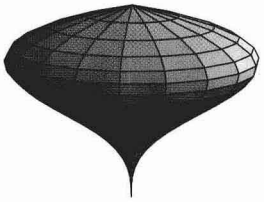

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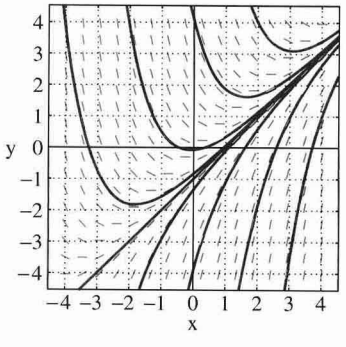

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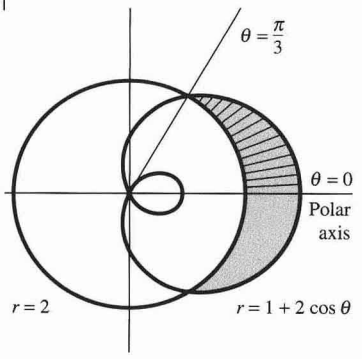

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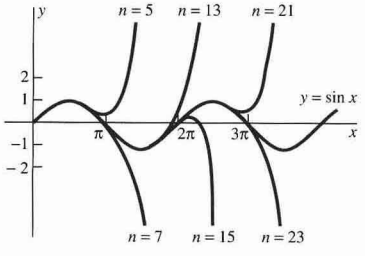

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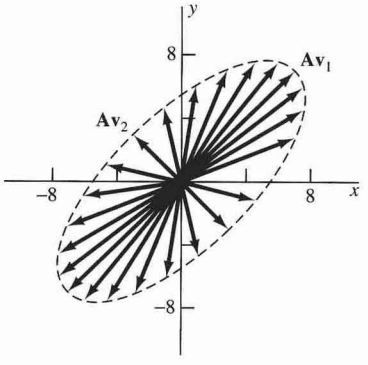

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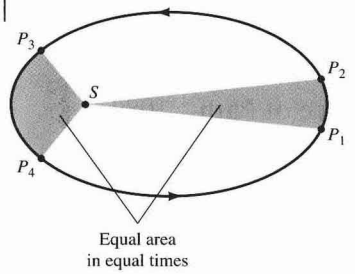

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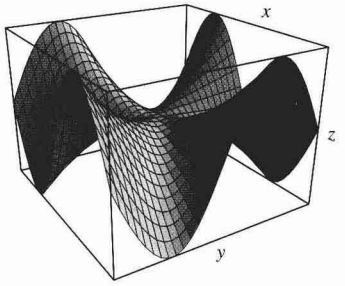

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