

TENTH EDITION

CALCULUS

Late Transcendentals

HOWARD ANTON

IRL BIVENS

STEPHEN DAVIS

International Student Version

10th
EDITION

CALCULUS

LATE TRANSCENDENTALS
International Student Version

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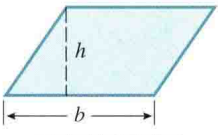
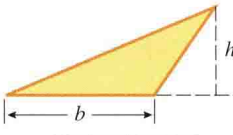
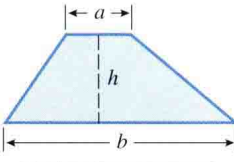
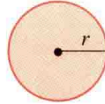
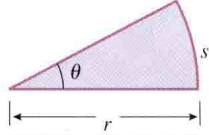
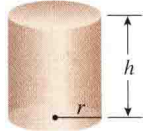
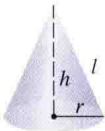
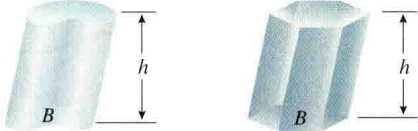
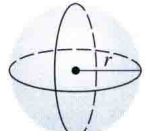
ISBN: 978-1-11809248-4

Printed in Asia

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GEOMETRY FORMULAS

A = area, S = lateral surface area, V = volume, h = height, B = area of base, r = radius, l = slant height, C = circumference, s = arc length

Parallelogram	Triangle	Trapezoid	Circle	Sector
 $A = bh$	 $A = \frac{1}{2}bh$	 $A = \frac{1}{2}(a + b)h$	 $A = \pi r^2, C = 2\pi r$	 $A = \frac{1}{2}r^2\theta, s = r\theta$ (θ in radians)
Right Circular Cylinder	Right Circular Cone	Any Cylinder or Prism with Parallel Bases		Sphere
 $V = \pi r^2 h, S = 2\pi r h$	 $V = \frac{1}{3}\pi r^2 h, S = \pi r l$	 $V = Bh$		 $V = \frac{4}{3}\pi r^3, S = 4\pi r^2$

ALGEBRA FORMULAS

THE QUADRATIC FORMULA	THE BINOMIAL FORMULA
The solutions of the quadratic equation $ax^2 + bx + c = 0$ are $x = \frac{-b \pm \sqrt{b^2 - 4ac}}{2a}$	$(x + y)^n = x^n + nx^{n-1}y + \frac{n(n-1)}{1 \cdot 2}x^{n-2}y^2 + \frac{n(n-1)(n-2)}{1 \cdot 2 \cdot 3}x^{n-3}y^3 + \dots + nxy^{n-1} + y^n$ $(x - y)^n = x^n - nx^{n-1}y + \frac{n(n-1)}{1 \cdot 2}x^{n-2}y^2 - \frac{n(n-1)(n-2)}{1 \cdot 2 \cdot 3}x^{n-3}y^3 + \dots \pm nxy^{n-1} \mp y^n$

TABLE OF INTEGRALS

BASIC FUNCTIONS

- | | |
|---|---|
| <ol style="list-style-type: none"> 1. $\int u^n du = \frac{u^{n+1}}{n+1} + C$ 2. $\int \frac{du}{u} = \ln u + C$ 3. $\int e^u du = e^u + C$ 4. $\int \sin u du = -\cos u + C$ 5. $\int \cos u du = \sin u + C$ 6. $\int \tan u du = \ln \sec u + C$ 7. $\int \sin^{-1} u du = u \sin^{-1} u + \sqrt{1 - u^2} + C$ 8. $\int \cos^{-1} u du = u \cos^{-1} u - \sqrt{1 - u^2} + C$ 9. $\int \tan^{-1} u du = u \tan^{-1} u - \ln \sqrt{1 + u^2} + C$ | <ol style="list-style-type: none"> 10. $\int a^u du = \frac{a^u}{\ln a} + C$ 11. $\int \ln u du = u \ln u - u + C$ 12. $\int \cot u du = \ln \sin u + C$ 13. $\int \sec u du = \ln \sec u + \tan u + C$
 $= \ln \left \tan \left(\frac{1}{4}\pi + \frac{1}{2}u \right) \right + C$ 14. $\int \csc u du = \ln \csc u - \cot u + C$
 $= \ln \left \tan \frac{1}{2}u \right + C$ 15. $\int \cot^{-1} u du = u \cot^{-1} u + \ln \sqrt{1 + u^2} + C$ 16. $\int \sec^{-1} u du = u \sec^{-1} u - \ln u + \sqrt{u^2 - 1} + C$ 17. $\int \csc^{-1} u du = u \csc^{-1} u + \ln u + \sqrt{u^2 - 1} + C$ |
|---|---|

RECIPROCAL OF BASIC FUNCTIONS

18. $\int \frac{1}{1 \pm \sin u} du = \tan u \mp \sec u + C$
19. $\int \frac{1}{1 \pm \cos u} du = -\cot u \pm \csc u + C$
20. $\int \frac{1}{1 \pm \tan u} du = \frac{1}{2}(u \pm \ln |\cos u \pm \sin u|) + C$
21. $\int \frac{1}{\sin u \cos u} du = \ln |\tan u| + C$
22. $\int \frac{1}{1 \pm \cot u} du = \frac{1}{2}(u \mp \ln |\sin u \pm \cos u|) + C$
23. $\int \frac{1}{1 \pm \sec u} du = u + \cot u \mp \csc u + C$
24. $\int \frac{1}{1 \pm \csc u} du = u - \tan u \pm \sec u + C$
25. $\int \frac{1}{1 \pm e^u} du = u - \ln(1 \pm e^u) + C$

POWERS OF TRIGONOMETRIC FUNCTIONS

26. $\int \sin^2 u du = \frac{1}{2}u - \frac{1}{4}\sin 2u + C$
27. $\int \cos^2 u du = \frac{1}{2}u + \frac{1}{4}\sin 2u + C$
28. $\int \tan^2 u du = \tan u - u + C$
29. $\int \sin^n u du = -\frac{1}{n}\sin^{n-1}u \cos u + \frac{n-1}{n}\int \sin^{n-2}u du$
30. $\int \cos^n u du = \frac{1}{n}\cos^{n-1}u \sin u + \frac{n-1}{n}\int \cos^{n-2}u du$
31. $\int \tan^n u du = \frac{1}{n-1}\tan^{n-1}u - \int \tan^{n-2}u du$
32. $\int \cot^2 u du = -\cot u - u + C$
33. $\int \sec^2 u du = \tan u + C$
34. $\int \csc^2 u du = -\cot u + C$
35. $\int \cot^n u du = -\frac{1}{n-1}\cot^{n-1}u - \int \cot^{n-2}u du$
36. $\int \sec^n u du = \frac{1}{n-1}\sec^{n-2}u \tan u + \frac{n-2}{n-1}\int \sec^{n-2}u du$
37. $\int \csc^n u du = -\frac{1}{n-1}\csc^{n-2}u \cot u + \frac{n-2}{n-1}\int \csc^{n-2}u du$

PRODUCTS OF TRIGONOMETRIC FUNCTIONS

38. $\int \sin mu \sin nu du = -\frac{\sin(m+n)u}{2(m+n)} + \frac{\sin(m-n)u}{2(m-n)} + C$
39. $\int \cos mu \cos nu du = \frac{\sin(m+n)u}{2(m+n)} + \frac{\sin(m-n)u}{2(m-n)} + C$
40. $\int \sin mu \cos nu du = -\frac{\cos(m+n)u}{2(m+n)} - \frac{\cos(m-n)u}{2(m-n)} + C$
41. $\int \sin^m u \cos^n u du = -\frac{\sin^{m-1}u \cos^{n+1}u}{m+n} + \frac{m-1}{m+n}\int \sin^{m-2}u \cos^n u du$
 $= \frac{\sin^{m+1}u \cos^{n-1}u}{m+n} + \frac{n-1}{m+n}\int \sin^m u \cos^{n-2}u du$

PRODUCTS OF TRIGONOMETRIC AND EXPONENTIAL FUNCTIONS

42. $\int e^{au} \sin bu du = \frac{e^{au}}{a^2 + b^2}(a \sin bu - b \cos bu) + C$
43. $\int e^{au} \cos bu du = \frac{e^{au}}{a^2 + b^2}(a \cos bu + b \sin bu) + C$

POWERS OF u MULTIPLYING OR DIVIDING BASIC FUNCTIONS



44. $\int u \sin u du = \sin u - u \cos u + C$
45. $\int u \cos u du = \cos u + u \sin u + C$
46. $\int u^2 \sin u du = 2u \sin u + (2 - u^2) \cos u + C$
47. $\int u^2 \cos u du = 2u \cos u + (u^2 - 2) \sin u + C$
48. $\int u^n \sin u du = -u^n \cos u + n \int u^{n-1} \cos u du$
49. $\int u^n \cos u du = u^n \sin u - n \int u^{n-1} \sin u du$
50. $\int u^n \ln u du = \frac{u^{n+1}}{(n+1)^2}[(n+1) \ln u - 1] + C$
51. $\int u e^u du = e^u(u-1) + C$
52. $\int u^n e^u du = u^n e^u - n \int u^{n-1} e^u du$
53. $\int u^n a^u du = \frac{u^n a^u}{\ln a} - \frac{n}{\ln a} \int u^{n-1} a^u du + C$
54. $\int \frac{e^u du}{u^n} = -\frac{e^u}{(n-1)u^{n-1}} + \frac{1}{n-1} \int \frac{e^u du}{u^{n-1}}$
55. $\int \frac{a^u du}{u^n} = -\frac{a^u}{(n-1)u^{n-1}} + \frac{\ln a}{n-1} \int \frac{a^u du}{u^{n-1}}$
56. $\int \frac{du}{u \ln u} = \ln |\ln u| + C$

POLYNOMIALS MULTIPLYING BASIC FUNCTIONS

57. $\int p(u)e^{au} du = \frac{1}{a}p(u)e^{au} - \frac{1}{a^2}p'(u)e^{au} + \frac{1}{a^3}p''(u)e^{au} - \dots$ [signs alternate: + - + - ...]
58. $\int p(u) \sin au du = -\frac{1}{a}p(u) \cos au + \frac{1}{a^2}p'(u) \sin au + \frac{1}{a^3}p''(u) \cos au - \dots$ [signs alternate in pairs after first term: + + - - + + - - ...]
59. $\int p(u) \cos au du = \frac{1}{a}p(u) \sin au + \frac{1}{a^2}p'(u) \cos au - \frac{1}{a^3}p''(u) \sin au - \dots$ [signs alternate in pairs: + + - - + + - - ...]

Calculus provides a way of viewing and analyzing the physical world. As with all mathematics courses, calculus involves equations and formulas. However, if you successfully learn to use all the formulas and solve all of the problems in the text but do not master the underlying *ideas*, you will have missed the most important part of calculus. If you master these ideas, you will have a widely applicable tool that goes far beyond textbook exercises.

Before starting your studies, you may find it helpful to leaf through this text to get a general feeling for its different parts:

- The opening page of each chapter gives you an overview of what that chapter is about, and the opening page of each section within a chapter gives you an overview of what that section is about. To help you locate specific information, sections are subdivided into topics that are marked with a box like this ■.
- Each section ends with a set of exercises. The answers to most odd-numbered exercises appear in the back of the book. If you find that your answer to an exercise does not match that in the back of the book, do not assume immediately that yours is incorrect—there may be more than one way to express the answer. For example, if your answer is $\sqrt{2}/2$ and the text answer is $1/\sqrt{2}$, then both are correct since your answer can be obtained by “rationalizing” the text answer. In general, if your answer does not match that in the text, then your best first step is to look for an algebraic manipulation or a trigonometric identity that might help you determine if the two answers are equivalent. If the answer is in the form of a decimal approximation, then your answer might differ from that in the text because of a difference in the number of decimal places used in the computations.
- The section exercises include regular exercises and four special categories: *Quick Check*, *Focus on Concepts*, *True/False*, and *Writing*.
 - The *Quick Check* exercises are intended to give you quick feedback on whether you understand the key ideas in the section; they involve relatively little computation, and have answers provided at the end of the exercise set.
 - The *Focus on Concepts* exercises, as their name suggests, key in on the main ideas in the section.
 - *True/False* exercises focus on key ideas in a different way. You must decide whether the statement is true in *all possible circumstances*, in which case you would declare it to be “true,” or whether there are some circumstances in which it is not true, in which case you would declare it to be “false.” In each such exercise you are asked to “Explain your answer.” You might do this by noting a theorem in the text that shows the statement to be true or by finding a particular example in which the statement is not true.
- *Writing* exercises are intended to test your ability to explain mathematical ideas in words rather than relying solely on numbers and symbols. All exercises requiring writing should be answered in complete, correctly punctuated logical sentences—not with fragmented phrases and formulas.
- Each chapter ends with two additional sets of exercises: *Chapter Review Exercises*, which, as the name suggests, is a select set of exercises that provide a review of the main concepts and techniques in the chapter, and *Making Connections*, in which exercises require you to draw on and combine various ideas developed throughout the chapter.
- Your instructor may choose to incorporate technology in your calculus course. Exercises whose solution involves the use of some kind of technology are tagged with icons to alert you and your instructor. Those exercises tagged with the icon  require graphing technology—either a graphing calculator or a computer program that can graph equations. Those exercises tagged with the icon  require a computer algebra system (CAS) such as *Mathematica*, *Maple*, or available on some graphing calculators.
- At the end of the text you will find a set of four appendices covering various topics such as a detailed review of trigonometry and graphing techniques using technology. Inside the front and back covers of the text you will find endpapers that contain useful formulas.
- The ideas in this text were created by real people with interesting personalities and backgrounds. Pictures and biographical sketches of many of these people appear throughout the book.
- Notes in the margin are intended to clarify or comment on important points in the text.

A Word of Encouragement

As you work your way through this text you will find some ideas that you understand immediately, some that you don't understand until you have read them several times, and others that you do not seem to understand, even after several readings. Do not become discouraged—some ideas are intrinsically difficult and take time to “percolate.” You may well find that a hard idea becomes clear later when you least expect it.

Web Sites for this Text

www.wiley.com/go/global/anton

WileyPLUS is a research-based online environment for effective teaching and learning.

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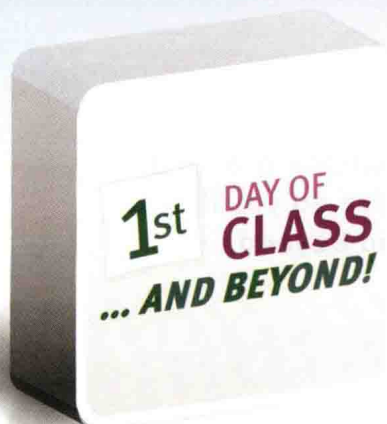
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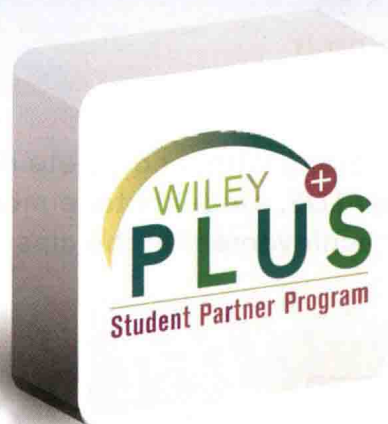


ALL THE HELP, RESOURCES, AND PERSONAL SUPPORT YOU AND YOUR STUDENTS NEED!

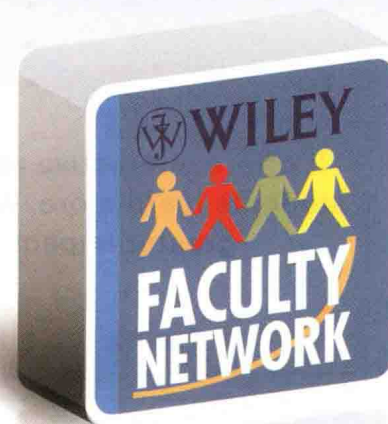
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About HOWARD ANTON

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 Emeritus 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. His textbook in linear algebra has won both the Textbook Excellence Award and the McGuffey Award from the Textbook Author's Association. 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 has served on the editorial boards of the MAA Problem Book series, the MAA Dolciani Mathematical Expositions series and *The College Mathematics Journal*. When he is not pursuing mathematics, Professor Bivens enjoys reading, juggling, swimming, and walking.

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. 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 has held several offices in the Southeastern section of the MAA, including chair and secretary-treasurer and has served on the MAA Board of Governors. He is currently a faculty consultant for the Educational Testing Service for the grading of the Advanced Placement Calculus Exam, webmaster for 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. 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.

To
my wife Pat and my children: Brian, David, and Lauren

In Memory of
my mother Shirley
my father Benjamin
my thesis advisor and inspiration, George Bachman
my benefactor in my time of need, Stephen Girard (1750-1831)
—HA

To
my son Robert
—IB

To
my wife Elisabeth
my children: Laura, Anne, and James
—SD



PREFACE

This tenth edition of *Calculus* maintains those aspects of previous editions that have led to the series' success—we continue to strive for student comprehension without sacrificing mathematical accuracy, and the exercise sets are carefully constructed to avoid unhappy surprises that can derail a calculus class.

All of the changes to the tenth edition were carefully reviewed by outstanding teachers comprised of both users and nonusers of the previous edition. The charge of this committee was to ensure that all changes did not alter those aspects of the text that attracted users of the ninth edition and at the same time provide freshness to the new edition that would attract new users.



NEW TO THIS EDITION

- Exercise sets have been modified to correspond more closely to questions in *WileyPLUS*. In addition, more *WileyPLUS* questions now correspond to specific exercises in the text.
- New applied exercises have been added to the book and existing applied exercises have been updated.
- Where appropriate, additional skill/practice exercises were added.



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 each instructor’s specific needs.

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 in an introductory treatment. 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 informed the reader when the arguments being presented are informal or motivational. Theory involving ϵ - δ arguments appears in separate sections so that they can be covered or not, as preferred by the instructor.

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.

Visualization 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.

Quick Check Exercises Each exercise set begins with approximately five exercises (answers included) that are designed to provide students with an immediate assessment of whether they have mastered key ideas from the section. They require a minimum of computation and are answered by filling in the blanks.

Focus on Concepts Exercises Each exercise set contains a clearly identified group of problems that focus on the main ideas of the section.

Technology Exercises Most sections include exercises that are designed to be solved using either a graphing calculator or a computer algebra system such as *Mathematica*, *Maple*, or the open source program *Sage*. These exercises are marked with an icon for easy identification.

Applicability of Calculus One of the primary goals of this text is to link calculus to the real world and the student's own experience. This theme is carried through in the examples and exercises.

Career Preparation 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.

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

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

Principles of Integral Evaluation The traditional Techniques of Integration is 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.

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 and bringing to life for the student the personalities of history's greatest mathematicians.

Margin Notes and Warnings These appear in the margins throughout the text to clarify or expand on the text exposition or to alert the reader to some pitfall.



SUPPLEMENTS

The **Web Projects (Expanding the Calculus Horizon)** referenced in the text can also be downloaded from the companion Web sites and from *WileyPLUS*.

The **Instructor's Solutions Manual** contains detailed solutions to all of the exercises in the text. The Instructor's Solutions Manual is also available in PDF format on the password-protected Instructor Companion Site at www.wiley.com/go/global/anton and in *WileyPLUS*.

Instructors can also access the following materials from the book companion site or *WileyPLUS*:

- The **Instructor's Manual** suggests time allocations and teaching plans for each section in the text. Most of the teaching plans contain a bulleted list of key points to emphasize. The discussion of each section concludes with a sample homework assignment. The Instructor's Manual is available in PDF format on the password-protected Instructor Companion Site at www.wiley.com/go/global/anton and in *WileyPLUS*.
- **Interactive Illustrations** can be used in the classroom or computer lab to present and explore key ideas graphically and dynamically. They are especially useful for display of three-dimensional graphs in multivariable calculus.
- The **Computerized Test Bank** features more than 4000 questions—mostly algorithmically generated—that allow for varied questions and numerical inputs.
- **PowerPoint lecture slides** cover the major concepts and themes of each section of the book. Personal-Response System questions (“Clicker Questions”) appear at the end of each PowerPoint presentation and provide an easy way to gauge classroom understanding.
- **Additional calculus content** covers analytic geometry in calculus, mathematical modeling with differential equations and parametric equations, as well as an introduction to linear algebra.

WileyPLUS

WileyPLUS, Wiley's digital-learning environment, is loaded with all of the supplements listed on the previous page, and also features the following:

- **Homework management tools**, which easily allow you to assign and grade algorithmic questions, as well as gauge student comprehension.
- **Algorithmic** questions with randomized numeric values and an answer-entry palette for symbolic notation are provided online through *WileyPLUS*. Students can click on “help” buttons for hints, link to the relevant section of the text, show their work or query their instructor using a white board, or see a step-by-step solution (depending on instructor-selecting settings).
- **Interactive Illustrations** can be used in the classroom or computer lab, or for student practice.

x Supplements

- **QuickStart** predesigned reading and homework assignments. Use them as-is or customize them to fit the needs of your classroom.
- The **e-book**, which is an exact version of the print text but also features hyperlinks to questions, definitions, and supplements for quicker and easier support.
- **Guided Online (GO) Tutorial Exercises** that prompt students to build solutions step by step. Rather than simply grading an exercise answer as wrong, GO tutorial problems show students precisely where they are making a mistake.
- **Are You Ready?** quizzes gauge student mastery of chapter concepts and techniques and provide feedback on areas that require further attention.
- **Algebra and Trigonometry Refresher** quizzes provide students with an opportunity to brush up on the material necessary to master calculus, as well as to determine areas that require further review.

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ACKNOWLEDGMENTS

It has been our good fortune to have the advice and guidance of many talented people whose knowledge and skills have enhanced this book in many ways. For their valuable help we thank the following people.

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xii Acknowledgments

- Jerome Heaven, *Indiana Tech*
Greg Henderson, *Hillsborough Community College*
Patricia Henry, *Drexel University*
Danrun Huang, *St. Cloud State University*
Alvaro Islas, *University of Central Florida*
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We would also like to thank Celeste Hernandez and Roger Lipsett for their accuracy check of the tenth edition. Thanks also go to Tamas Wiandt for revising the solutions manuals, and Przemyslaw Bogacki for accuracy checking those solutions; Brian Camp and Lyle Smith for their revision of the Student Study Guide; Jim Hartman for his revision of the Instructor's Manual; Ann Ostberg for revising the PowerPoint slides; Beverly Fusfield for creating new GO Tutorials, and Mark McKibben for accuracy checking these new tutorials. We also appreciate the feedback we received from Mark Dunster, Cecelia Knoll, and Michael Rosenthal on selected *WileyPLUS* problems.