SIXTH EDITION

Calculus

VOLUME THREE

A NEW HORIZON

HOWARD ANTON

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A New Horizon

VOLUME III
SIXTH EDITION

HOWARD ANTON
Drexel University

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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 missile tracking problems for 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 on applications of mathematics. He is best known for his textbooks in mathematics, which are among the most widely used in the world. There are currently more than ninety versions of his books, including translations into Spanish, Arabic, Portuguese, Italian, Indonesian, French, Japanese, Chinese, Hebrew, and German. Dr. Anton has an avid interest in computer technology as it relates to mathematical education and publishing. He has developed pedagogical software for teaching calculus and linear algebra as well as various software programs for the publishing industry that automate the production of four-color mathematical text and art. For relaxation he enjoys traveling and photography.

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

In Memory of
My Mother Shirley
Stephen Girard (1750–1831)—Benefactor
Albert Herr—Esteemed Colleague and Contributor

A Note from the Author

When I began writing the first edition of this calculus text almost 25 years ago, the task, though daunting, was straightforward in that the content and organization of a standard calculus course was nearly universal—the challenge for me at that time was to present the material in a livelier style and with greater clarity than my predecessors. Since this calculus text is still among the most widely used in the world, I take comfort that the goals I set for myself as a young writer and mathematician have been achieved.

However, times are changing, and the era of a standard and universal calculus course seems destined for the repository of slide rules and three-cent stamps. We are witnessing a lot of experimentation with the content, organization, and goals of calculus—some of which has been successful and some of which has not. Thus, my challenge in writing the sixth edition has been to create a text that has all of the strengths of the earlier editions, yet incorporates those new ideas that are clearly important and have withstood the objective scrutiny of skilled and thoughtful teachers.

In preparing for this edition, I sought advice from outstanding teachers at a wide variety of institutions. Needless to say, I received a diversity of opinions—some reviewers advised against any major changes, arguing that the book was already clearly written and working well in the classroom, while others felt that major changes were required to incorporate technology and make the book more contemporary. I listened carefully, and the lively discussions that followed helped me formulate my philosophy for the new edition. Many of the specific changes are itemized in the preface, but here are some of the general goals:

- Add graphing calculator and CAS materials to the text in a way that will allow students who have those tools to use them but that will not prevent the text from being used by those students who do not have access to that technology.
- Place more emphasis on mathematical modeling and applications.
- Incorporate new examples and exercises that will be meaningful to today's students and will more accurately convey the role of calculus in the real world.
- Widen the variety of exercises to focus more on *conceptual understanding* through conjecture, multi-step analysis, expository writing, and what-if analysis.

In addition, I wanted to provide some optional innovative materials that would capture the student's interest and provide the kind of problem-solving experience that he or she might find in a research or industrial setting. This gave birth to an exciting set of modules that we have called *Expanding the Calculus Horizon*. These modules appear at the ends of selected chapters and each has an optional Internet component that we hope will grow dynamically over time with input from teachers and students.

In developing this edition I have stood firm on two principles that were adhered to in earlier editions:

- The text material is presented at a mathematical level that is suitable for students who will embark on careers in engineering and science.
- It remains a primary goal of the text to teach the student clear, logical, mathematical thinking. Informal discussions play an important motivational role in the exposition and are used extensively, but eventually I want the student to be able to read and understand the language of mathematics.

Although this edition has many changes and new features, they have been implemented in a *flexible* way that will accommodate a wide variety of teaching philosophies. Thus, I am confident that professors who have had positive experiences with earlier editions will be comfortable with this revision, and I am hopeful that those professors who are looking for a contemporary text with an established history of success in the classroom will be pleased with the innovations in this new edition.

Sincerely,

Howard Anton

Howard Anton

From Student to Student

At times the words of a complete stranger are difficult to accept. That is why I am about to take this first opportunity to introduce myself. Hopefully by revealing a bit about myself and how I relate to this textbook may help you find these words more compelling.

Hello, my name is Ajay Arora and I am an Electrical Engineering student at McMaster University in Hamilton, Canada. I too was in your place when I began my entry into the much dreaded field of *CALCULUS*. The vast amounts of rate of change and antiderivative problems were overwhelming. With a little struggle and hard work, I successfully completed that course only to be faced with three more advanced level calculus courses. What I am about to write is the unbiased truth on how you can be successful in calculus and how this textbook will assist you on your journey.

I have been a member of the Student Advisory Board for this textbook for over a year now. The committee came together as a venture from the authors and publisher to get more student input in the development stages instead of simply focusing on feedback when the book was published. After a chapter was completed by the author, each student committee member evaluated, commented, and in some cases, recommended alternative approaches. These tasks involved lots of special deliveries, E-mails, faxes, telephone calls, conference calls, and of course, a whole lot of calculus! But in the end it was a total rewarding experience.

How many times have you asked yourself, "Is math really useful?" Or how about, "Will I ever use calculus in the real world?" I know I have! This textbook will definitely help you answer some of these questions with true applications of the theories you learn. The modules entitled Expanding the Calculus Horizon have been included for precisely that purpose. Every module has been critiqued extensively by the Student Advisory Board, and I encourage you to try them. Not only will these applications of calculus surprise you, but they may actually help give you direction in a field that you might want to pursue after college.

I wish you success in this course, as well as the many others you will face during your college career. Good Luck!

Sincerely,

Ajay Arora
McMaster University

Best Wishes for Success from the Student Advisory Board

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PREFACE

ABOUT THIS EDITION

This is a major revision. In keeping with current trends in calculus, the goal for this edition is to focus more on ***conceptual understanding*** and ***applicability*** of the subject matter. In designing this edition, we worked closely with a talented team of reviewers to ensure that the book is sufficiently ***flexible*** that it will continue to meet the needs of those using the last edition and at the same time provide a fresh approach for those instructors who are taking their calculus course in a new direction. Some of the more significant changes are as follows:

Technology This edition provides extensive materials for instructors who want to use graphing calculators or computer algebra systems. However, these materials are implemented in a way that allows the text to be used in courses where technology is used heavily, moderately, or not at all. To provide a sound foundation for the technology material, I have added a new section entitled Graphing Functions on Calculators and Computers; Computer Algebra Systems (Section 1.3).

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, modeling from experimental data by curve fitting, applications, expository report writing, and so forth.

Mathematical Modeling Mathematical modeling plays a more prominent role in this edition. The concept of a mathematical model is introduced in Section 1.5 and is used extensively thereafter. The Horizon module for Chapter 5 discusses how to obtain mathematical models from experimental data. In Section 10.3 we discuss mathematical modeling with differential equations, and in Section 11.10 we discuss mathematical modeling with Taylor series. The Horizon module for Chapter 17 develops a mathematical model of a hurricane.

Applicability of Calculus One of the goals in this edition is to link calculus more closely to the real world and to the student's own experience. This theme starts with the Introduction and is carried through in the modules, examples, and exercises. Applications appearing in exercises and examples are carefully chosen to be sufficiently simple that they do not divert time from learning important mathematical fundamentals. More extensive applications appear in various Horizon modules.

Earlier 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 10.

Quicker Entry to Functions Chapter 1 begins immediately with functions, and the precalculus material that formed the first chapter in earlier editions has been moved to the appendix.

For the Reader This element is new. At various points in the exposition the student is assigned a brief task. Some tasks are appropriate for all readers, while others are

appropriate only for readers who have a graphing calculator or a CAS. The tasks for all readers are designed to immerse the student 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.

Earlier Logarithms and Exponentials Logarithmic and exponential functions are introduced in Chapter 4 from the exponent point of view and then revisited in Section 7.9 from the integral point of view. This provides a richer variety of functions to work with earlier in the text, fits in better with the discussions of modeling, and makes for a less fragmented presentation of the analysis of graphs. However, for instructors who prefer a later presentation of logarithmic and exponential functions, there is a guide for doing this on pages xvi and xvii below.

Early Parametric Option There is a new option for introducing parametric curves in Section 1.7 of Chapter 1 and revisiting the material in Chapter 12, where calculus-related issues are discussed. Instructors who prefer the traditional late discussion of parametric equations will have no problem teaching Section 1.7 as part of Chapter 12 or 13.

More Variety in Exercises The exercise sets have been revised extensively to create a richer variety—there are many more exercises that include conjecture, exploration, multistep analysis, and expository writing. The goal has been to put more focus on *conceptual understanding*. There are also many new exercises that are intended to be solved using a graphing calculator or a CAS. These are marked with icons for easy identification.

Analysis of Functions The old "curve-sketching" material has been replaced by Sections 5.1–5.3 on the Analysis of Functions. The name change reflects a more contemporary approach to the material—there is more emphasis on the interplay between technology and calculus and more focus on the problem of finding a *complete graph*, that is, a graph that contains all of the significant features of concern.

Principles of Integral Evaluation The old "Techniques of Integration" has been renamed Principles of Integral Evaluation to reflect its more contemporary approach to the material. The chapter has been condensed and there is now more emphasis on general methods and less on tricks for evaluating complicated or obscure integrals. The section entitled Using Integral Tables and Computer Algebra Systems has been expanded and rewritten extensively.

Supplementary Exercises Supplementary exercises have been added at the ends of chapters.

New Appendix on Solving Polynomial Equations Appendix F, entitled Solving Polynomial Equations, is new. It reviews the Factor Theorem, the Remainder Theorem, and procedures for finding rational roots. Many students are weak on this material, yet it plays an important role in determining whether a polynomial graph generated on a calculator or computer is complete.

Rule of Four The "rule of four" refers to the presentation of material from the verbal, algebraic, visual, and numerical points of view. It is used more extensively in this edition, where appropriate.

OTHER FEATURES

Internet An internet site http://www.wiley.com/college/anton has been established to complement the text. This site contains additional Horizon modules and technology materials. The site is experimental, but we expect it to grow dynamically over time.

Flexibility This edition has a built-in flexibility that is designed to serve a broad spectrum of calculus philosophies, ranging from traditional to reform. Graphing technology can be used heavily, moderately, or not at all; and the order of presentation of many sections can be permuted to accommodate specific course needs.

Trigonometry Review Deficiencies in trigonometry plague many students, so I 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 in this edition. 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 student.

Graded Exercise Sets Section Exercise Sets are graded to begin with routine problems and progress gradually toward problems of greater difficulty. However, in the Supplementary Exercises I have opted not to grade the exercises by level of difficulty to avoid giving 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. My goal is to present precise mathematics to the fullest extent possible for the freshman audience, but where clarity and rigor conflict I choose clarity. However, I believe it to be essential that the student understand the difference between a careful proof and an informal argument, so I try to make it clear to the reader when arguments are informal. Theory involving δ-ϵ arguments appear in separate sections, so they can be bypassed if desired.

Mathematical Level This book is written at a mathematical level that is suitable for students planning on careers in engineering or science.

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

Student Review A Student Advisory Board was actively involved in the development process of this edition to provide information on pedagogical clarity and to advise on the development of examples, exercises, and modules that students would find interesting and relevant.

SOME ORGANIZATION CHANGES FROM FIFTH EDITION

- Much of the precalculus material has been moved to appendices to allow for an earlier presentation of functions. However, where appropriate, we have included quick summaries of review material in the body of the text.
- The material on logarithmic and exponential functions has been reorganized, so it can be covered in the first semester (an early transcendental presentation). There is a guide on the next page for implementing a late transcendental presentation.
- The first 13 chapters of the fifth edition are covered in the first 12 chapters of the sixth edition.
- The first 7 chapters of the fifth edition correspond to the first 9 chapters of the sixth edition. However, ***the number of sections is about the same***, so there is ***no increase in the number of lectures required to cover the material***. The new subdivision is more natural in that the chapter titles now reflect the chapter content more accurately.
- In the sixth edition, as in the fifth edition, instructors teaching on the semester system should have no trouble covering material on integration in the first semester.
- Chapter 11 on Infinite Series has been condensed from 12 sections to 10, and the material has been reorganized so that Taylor polynomials and Taylor series appear earlier. This makes it possible to cover these topics without covering the entire chapter.
- The material on analytic geometry and polar coordinates, which occupied Chapters 12 and 13 in the fifth edition, is covered in Chapter 12 of the sixth edition.
- L'Hôpital's rule was moved to an earlier position, so it can be used to analyze the end-behavior of logarithmic and exponential functions.
- The two parts to the Fundamental Theorem of Calculus, which appeared in separate sections of the fifth edition, now appear together in the same section (Section 7.6).

Late Transcendental Option

In keeping with current trends, Chapters 1 to 8 of this text are organized so that the basic material on logarithmic and exponential functions is covered in the first semester (commonly called an "early transcendental" presentation). This is achieved by introducing logarithms informally from the exponent point of view (Section 4.2) and deferring the integral representation of the natural logarithm (Section 7.9). However, we have included the following guide for instructors who prefer to cover logarithmic and exponential functions in the second semester (as in the fifth edition). Depending on your preference, you can place the deferred material after Chapter 7 or after Chapter 8. The guide shows how to place it after Chapter 8. To place it after Chapter 7, ignore the exercise modifications listed for Chapter 8.

	Section	Text Modifications (bulleted)	Exercise Modifications
1	1.1	Functions and Analysis of Graphical Information	
2	1.2	Properties of Functions	
3	1.3	Graphing Functions on Calculators and Computers	
4	1.4	New Functions from Old	
5	1.5	Mathematical Models; Linear Models	
6	1.6	Families of Functions	
7	1.7	Parametric Equations	
8	2.1	Limits (Intuitive)	
9	2.2	Limits (Computational)	
10	2.3	Limits (Rigorous)	
11	2.4	Continuity	
12	2.5	Limits / Continuity of Trigonometric Functions	
13	3.1	Tangent Lines and Rates of Change	
14	3.2	The Derivative	
15	3.3	Techniques of Differentiation	
16	3.4	Derivatives of Trigonometric Functions	
17	3.5	The Chain Rule	
18	3.6	Local Linear Approximation; Differentials	
19	4.3	Implicit Differentiation • Defer the concluding subsection on derivatives of inverse functions (pp. 252–253).	Defer Exercises 10, 53–56.
20	4.6	Related Rates • Defer the alternative solution to Example 3 at the bottom of p. 272.	Defer Exercise 37. Defer Supplementary Exercises 1–6, 8–14, 16–24.
21	5.1	Analysis I: Increase, Decrease, Concavity • Defer Examples 6(a) and 6(c) on p. 295.	Defer Exercises 21–24, 38, 41, 53.
22	5.2	Analysis II: Relative Extrema	Defer Exercises 15, 31, 32, 39–42, 50, 51.
23	5.3	Analysis III: Applying Technology • Defer Example 8 and the discussion of logistic curves that follows it (pp. 316–319). • Defer the Horizon Module for Chapter 5.	Defer Exercises 39–48, 53–55, 69, 70. Defer Supplementary Exercises 17–24, 33, 37–39.
24	6.1	Absolute Maxima and Minima	Defer Exercises 31, 32, 44.
25	6.2	Applied Maximum and Minimum Problems	Defer Exercise 15.
26	6.3	Rectilinear Motion	Defer Exercise 16.
27	6.4	Newton's Method	Defer Exercises 14, 16
28	6.5	Rolle's Theorem; Mean-Value Theorem	Defer Exercise 36 Defer Supplementary Exercises 7(d), 8(d), 22.

29	7.1	An Overview of the Area Problem	Defer Exercise 9.
30	7.2	Indefinite Integral; Integral Curves; Direction Fields • Defer integration formulas (6), (10), (11) in Table 7.2.1 on p. 384. • Defer the last (fifth) integral in Example 2 on p. 385.	Defer Exercises 1(b), 19, 20, 25, 34, 39(b).
31	7.3	Integration by Substitution • Defer Example 5, p. 393. • Defer Example 7, p. 394.	Defer Exercises 2(e), 3(c), (d), (e), 5, 6, 19–22, 27, 28, 35, 36, 45–48, 54.
32	7.4	Sigma Notation	Defer Exercises 2(c), (e), 39(b).
33	7.5	The Definite Integral	Defer Exercises 6, 13, 14, 33(b), 38(a), 45(a).
34	7.6	The Fundamental Theorem of Calculus • Defer the first three of the four integrals in Example 5, p. 419.	Defer Exercises 7, 8, 19, 20, 24, 28(b), 45(b), 46(b), 55(b), 59.
35	7.7	Rectilinear Motion Revisited	Defer Exercises 13(b), 14(a), 23, 24, 27, 28, 53, 54.
36	7.8	Evaluating Definite Integrals by Substitution • Defer Example 2(a), p. 422. • Defer Example 3, p. 443.	Defer Exercises 2(a, b), 11, 12, 16, 21, 37, 38, 45–48. Defer Supplementary Exercises 12, 13, 14(c), 37, 39–41, 49.
37	8.1	Area Between Two Curves	Defer Exercise 13.
38	8.2	Volumes by Slicing; Disks and Washers	Defer Exercises 11, 12, 38.
39	8.3	Volumes by Cylindrical Shells	Defer Exercise 11.
40	8.4	Length of a Plane Curve	Defer Exercises 7, 13, 14, 15, 16.
41	8.5	Surface Area	Defer Exercises 13, 15, 22.
42	8.6	Work	
43	8.7	Fluid Pressure and Force	
44	4.1	Inverse Functions • Pick up material deferred from Section 4.3.	**Pick up Exercises:** Section 4.3 (53–56) Chapter 4 Supplementary (1, 6).
45	4.2	Logarithmic and Exponential Functions	**Pick up Exercises:** Section 4.3 (10) Chapter 4 Supplementary (5, 9, 17, 20–22).
46	4.4	Derivatives of Log and Exponential Functions • Pick up material deferred from Section 7.2. • Pick up material deferred from Section 5.3.	**Pick up Exercises:** Section 4.6 (37) Chapter 4 Supplementary (10, 12, 14, 16, 19, 23, 24) Section 5.1 (21–24, 38, 41, 53) Section 5.2 (15, 31, 32, 39–42, 50, 51) Section 5.3 (44, 53–55) Chapter 5 Supplementary (20, 33, 39) Section 6.1 (31, 32, 44) Section 6.2 (15) Section 6.3 (16) Section 6.4 (14, 16) Section 6.5 (36) Chapter 6 Supplementary (7(d), 8(d), 22). Chapter 7 (all deferred) Section 5.3 (69, 70) Chapter 8 (all deferred).
47	4.5	Derivatives of Inverse Trig Functions • Pick up material deferred from Section 4.6.	**Pick up Exercises:** Chapter 4 Supplementary (2, 8, 13, 18).
48	7.9	Logarithmic Functions; Integral Point of View	
49	8.8	Hyperbolic Functions and Hanging Cables	
50	4.7	L'Hôpital's Rules	**Pick up Exercises:** Chapter 4 Supplementary (3, 4, 11) Section 5.3 (39–43, 45–48) Chapter 5 Supplementary (17–19, 21–24, 37, 38).
		• Pick up Horizon module from Chapter 5.	

SUPPLEMENTS

RESOURCES FOR THE STUDENT

Student Resource and Survival CD

0-471-24608-5

This CD for IBM compatibles or Macintosh platforms provides students with an electronic form of detailed solutions to odd-numbered exercises, multiple choice and true–false sample tests for each section and chapter of the text, precalculus review material, and a brief introduction to those aspects of linear algebra that are of immediate concern to the calculus student. Two demonstration modules from the Windows-based multimedia calculus program *Calculus Connections, A Multimedia Adventure* are also available on this CD.

Student Resource Manual

0-471-24616-6

This manual provides students with detailed solutions to odd-numbered exercises and multiple choice and true–false sample tests for each section and chapter of the text.

RESOURCES FOR THE INSTRUCTOR

Hard copy and electronic resources are available for the instructor. These 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 requesting them from your local Wiley representative.

OTHER RESOURCES

We are proud to offer special pricing of the student educational versions of *MAPLE*™ or *MATHEMATICA*™ packaged with the sixth edition of Howard Anton's *Calculus* textbook. For pricing information, you can contact your local Wiley representative, email us at math@wiley.com, or call us at (800) 225-5945.

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