# CALCULUS

with CalcChat® and CalcYiew®

**11e** 





# CALCULUS

with CalcChat® and CalcYiew®

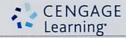
11e

### **Ron Larson**

The Pennsylvania State University The Behrend College

### **Bruce Edwards**

University of Florida





#### Calculus, Eleventh Edition Ron Larson, Bruce Edwards

Product Director: Terry Boyle Product Manager: Gary Whalen

Senior Content Developer: Stacy Green
Associate Content Developer: Samantha Lugtu

Product Assistant: Katharine Werring Media Developer: Lynh Pham Marketing Manager: Ryan Ahern

Content Project Manager: Jennifer Risden Manufacturing Planner: Doug Bertke Production Service: Larson Texts, Inc. Photo Researcher: Lumina Datamatics Text Researcher: Lumina Datamatics

Illustrator: Larson Texts, Inc. Text Designer: Larson Texts, Inc. Compositor: Larson Texts, Inc. Cover Designer: Larson Texts, Inc.

Cover photograph by Caryn B. Davis | carynbdavis.com

Cover background: iStockphoto.com/briddy\_

Umbilic Torus by Helaman Ferguson, donated to Stony Brook

University

The cover image is the Umbilic Torus statue created in 2012 by the famed sculptor and mathematician Dr. Helaman Ferguson. This statue weighs 10 tons and has a height of 24 feet. It is located at Stony Brook University in Stony Brook, New York. © 2018, 2014 Cengage Learning

ALL RIGHTS RESERVED. No part of this work covered by the copyright herein may be reproduced or distributed in any form or by any means, except as permitted by U.S. copyright law, without the prior written permission of the copyright owner.

For product information and technology assistance, contact us at Cengage Learning Customer & Sales Support, 1-800-354-9706.

For permission to use material from this text or product, submit all requests online at www.cengage.com/permissions.

Further permissions questions can be emailed to permissionrequest@cengage.com.

Library of Congress Control Number: 2016944973

Student Edition:

ISBN: 978-1-337-27534-7

Loose-leaf Edition: ISBN: 978-1-337-27557-6

Cengage Learning 20 Channel Center Street Boston, MA 02210

Cengage Learning is a leading provider of customized learning solutions with employees residing in nearly 40 different countries and sales in more than 125 countries around the world. Find your local representative at www.cengage.com.

Cengage Learning products are represented in Canada by Nelson Education, Ltd.

To learn more about Cengage Learning Solutions, visit www.cengage.com. Purchase any of our products at your local college store or at our preferred online store www.cengagebrain.com.

QR Code is a registered trademark of Denso Wave Incorporated

# Contents

P	D	Prep	aration for Calculus	1
		P.1	Graphs and Models 2	
		P.2	Linear Models and Rates of Change 10	
		P.3	Functions and Their Graphs 19	
		P.4	Review of Trigonometric Functions 31	
			Review Exercises 41	
			P.S. Problem Solving 43	
1	D	Limit	ts and Their Properties	45
		1.1	A Preview of Calculus 46	
		1.2	Finding Limits Graphically and Numerically 52	
		1.3	Evaluating Limits Analytically 63	
		1.4	Continuity and One-Sided Limits 74	
		1.5	Infinite Limits 87	
			Section Project: Graphs and Limits of	
			Trigonometric Functions 94	
			Review Exercises 95	
			P.S. Problem Solving 97	
2	_	Diffe	erentiation	99
~				33
		2.1	The Derivative and the Tangent Line Problem 100	
		2.2	Basic Differentiation Rules and Rates of Change 110	
		2.3	Product and Quotient Rules and Higher-Order Derivatives 122	
		2.4	The Chain Rule 133	
		2.5	Implicit Differentiation 144	
			Section Project: Optical Illusions 151	
		2.6	Related Rates 152	
			Review Exercises 161	
			P.S. Problem Solving 163	
2	_	Ann	lications of Differentiation	165
J		100		165
		3.1	Extrema on an Interval 166	
		3.2	Rolle's Theorem and the Mean Value Theorem 174	
		3.3	Increasing and Decreasing Functions and the First Derivative Test 181	
			Section Project: Even Fourth-Degree Polynomials 190	
		3.4	Concavity and the Second Derivative Test 191	
		3.5	Limits at Infinity 199	
		3.6	A Summary of Curve Sketching 209	
		3.7	Optimization Problems 219	
			Section Project: Minimum Time 228	
		3.8	Newton's Method 229	
		3.9	Differentials 235	
			Review Exercises 242	
			P.S. Problem Solving 245	

				247
4	D	Integ	gration	
		4.1	Antiderivatives and Indefinite Integration 248	
		4.2	Area 258	
		4.3	Riemann Sums and Definite Integrals 270	
		4.4	The Fundamental Theorem of Calculus 281	
			Section Project: Demonstrating the	
			Fundamental Theorem 295	
		4.5	Integration by Substitution 296	
			Review Exercises 309	
			P.S. Problem Solving 311	
-		Loga	arithmic, Exponential, and	
5	0	Othe	er Transcendental Functions	313
		5.1	The Natural Logarithmic Function: Differentiation 314	
		5.2	The Natural Logarithmic Function: Integration 324 Inverse Functions 333	
		5.3	Exponential Functions: Differentiation and Integration 342	
		5.4 5.5	Bases Other than e and Applications 352	
		5.5	Section Project: Using Graphing Utilities to	
			Estimate Slope 361	
		5.6	Indeterminate Forms and L'Hôpital's Rule 362	
		5.7	Inverse Trigonometric Functions: Differentiation 373	
		5.8	Inverse Trigonometric Functions: Integration 382	
		5.9	Hyperbolic Functions 390	
			Section Project: Mercator Map 399	
			Review Exercises 400	
			P.S. Problem Solving 403	
6	D	Diffe	rential Equations	405
_		6.1	Slope Fields and Euler's Method 406	
		6.2	Growth and Decay 415	
		6.3	Separation of Variables and the Logistic Equation 423	
		6.4	First-Order Linear Differential Equations 432	
			Section Project: Weight Loss 438	
			Review Exercises 439	
			P.S. Problem Solving 441	
7	D	Appl	ications of Integration	443
		7.1	Area of a Region Between Two Curves 444	
		7.2	Volume: The Disk Method 454	
		7.3	Volume: The Shell Method 465	
			Section Project: Saturn 473	
		7.4	Arc Length and Surfaces of Revolution 474	
		7.5	Work 485	
			Section Project: Pyramid of Khufu 493	
		7.6	Moments, Centers of Mass, and Centroids 494	
		7.7	Fluid Pressure and Fluid Force 505	
			Review Exercises 511	
			P.S. Problem Solving 513	

~	-	-	٠,	w.	*		9
100	•	.,	ы	м	п	ы	96

В	D	Integ	ration Techniques and Improper Integrals	515
		8.1	Basic Integration Rules 516	
		8.2	Integration by Parts 523	
		8.3	Trigonometric Integrals 532	
			Section Project: The Wallis Product 540	
		8.4	Trigonometric Substitution 541	
		8.5	Partial Fractions 550	
		8.6	Numerical Integration 559	
		8.7	Integration by Tables and Other Integration Techniques	566
		8.8	Improper Integrals 572	
			Review Exercises 583	
			P.S. Problem Solving 585	
9	_	Indias	to Cavino	587
J			te Series	567
		9.1	Sequences 588	
		9.2	Series and Convergence 599	
			Section Project: Cantor's Disappearing Table 608	
		9.3	The Integral Test and p-Series 609	
		9.4	Section Project: The Harmonic Series 615 Comparisons of Series 616	
		9.5	Alternating Series 623	
		9.6	The Ratio and Root Tests 631	
		9.7	Taylor Polynomials and Approximations 640	
		9.8	Power Series 651	
		9.9	Representation of Functions by Power Series 661	
		9.10	Taylor and Maclaurin Series 668	
			Review Exercises 680	
			P.S. Problem Solving 683	
0	D		cs, Parametric Equations, and	
٠	160		r Coordinates	685
		10.1	Conics and Calculus 686	
		10.2	Plane Curves and Parametric Equations 700	
			Section Project: Cycloids 709	
		10.3	Parametric Equations and Calculus 710	
		10.4	Polar Coordinates and Polar Graphs 719	
		10.5	Section Project: Cassini Oval 728	
		10.5	Area and Arc Length in Polar Coordinates 729 Polar Equations of Conics and Kepler's Laws 738	
		10.0	Review Exercises 746	
			P.S. Problem Solving 749	

-			
11 ⊳	Vec	tors and the Geometry of Space	751
	11.1	Vectors in the Plane 752	
	11.2	Space Coordinate /52	
	11.3	Space Coordinates and Vectors in Space 762	
	11.4	The Dot Product of Two Vectors 770	
	11.5	oross rioduct of two vectors in Space 775	
		Lines and Planes in Space 787	
	11.6	Section Project: Distances in Space 797 Surfaces in Space 798	
	11.7	Cylindrical and Spherical Coordinates 808	
		Review Exercises 815	
		P.S. Problem Solving 817	
		Section Colving 817	
12 ⊳	Vect	tor-Valued Functions	010
			819
	12.1	Vector-Valued Functions 820	
	12.2	Section Project: Witch of Agnesi 827	
	12.2	Differentiation and Integration of Vector-Valued	
	122	Functions 828	
	12.3	Velocity and Acceleration 836	
	12.4	Tangent Vectors and Normal Vectors 845	
	12.5	Arc Length and Curvature 855	
		Review Exercises 867	
		P.S. Problem Solving 869	
12 .	-		
13	Fund	ctions of Several Variables	871
	13.1	Introduction to Functions of Several Variables 872	
	13.2	Limits and Continuity 884	
	13.3	Partial Derivatives 894	
	13.4		
	13.5	Chain Rules for Functions of Several Variables 911	
	13.6	Directional Derivatives and Gradients 919	
	13.7	Tangent Planes and Normal Lines 931	
		Section Project: Wildflowers 939	
	13.8	Extrema of Functions of Two Variables 940	
	13.9	Applications of Extrema 948	
		Section Project: Building a Pipeline 955	
	13.10	The state of the s	
		Review Exercises 964	
		P.S. Problem Solving 967	
14 ⊳	Mult	iple Integration	969
	14.1	Iterated Integrals and Area in the Plane 970	
	14.2	Double Integrals and Volume 978	
	14.3	Change of Variables: Polar Coordinates 990	
	14.4	Center of Mass and Moments of Inertia 998	
		Section Project: Center of Pressure on a Sail 1005	
	14.5	Surface Area 1006	
		Section Project: Surface Area in Polar Coordinates 1012	
	14.6	Triple Integrals and Applications 1013	
	14.7	Triple Integrals in Other Coordinates 1024	
	10 10 10	Section Project: Wrinkled and Bumpy Spheres 1030	
	14.8	Change of Variables: Jacobians 1031	
		Review Exercises 1038	
		P.S. Problem Solving 1041	

15	D	Vect	or Analysis 1043
		15.1	Vector Fields 1044
		15.2	Line Integrals 1055
		15.3	Conservative Vector Fields and Independence of Path 1069
		15.4	Green's Theorem 1079
			Section Project: Hyperbolic and Trigonometric Functions 1087
		15.5	Parametric Surfaces 1088
		15.6	Surface Integrals 1098
			Section Project: Hyperboloid of One Sheet 1109
		15.7	Divergence Theorem 1110
		15.8	Stokes's Theorem 1118
			Review Exercises 1124

## 16 ► Additional Topics in Differential Equations (Online)\*

16.1 Exact First-Order Equations

P.S. Problem Solving 1127

- 16.2 Second-Order Homogeneous Linear Equations
- 16.3 Second-Order Nonhomogeneous Linear Equations Section Project: Parachute Jump
- 16.4 Series Solutions of Differential Equations
  Review Exercises
  P.S. Problem Solving

#### **Appendices**

Appendix A: Proofs of Selected Theorems A2

Appendix B: Integration Tables A3

Appendix C: Precalculus Review (Online)\*

Appendix D: Rotation and the General Second-Degree

Equation (Online)\*

Appendix E: Complex Numbers (Online)\*

Appendix F: Business and Economic Applications (Online)\*

Appendix G: Fitting Models to Data (Online)\*

Answers to All Odd-Numbered Exercises A7 Index A121

<sup>\*</sup>Available at the text-specific website www.cengagebrain.com

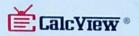
# 100% FREE

## Internet Resources at LarsonCalculus.com

- Interactive Examples powered by Wolfram's free CDF Player™
- · Videos explaining the concepts of calculus
- Three-Dimensional Graphs that can be viewed and rotated using Wolfram's CDF Player™
- Videos with Bruce Edwards explaining the proofs and theorems in the text
- · Editable Spreadsheets of the data sets in the text



CalcChat.com offers you the solutions to the odd-numbered exercises from the text. When the solutions are not enough, you can chat with an online tutor for live help. Visit the website for the tutors' availability.



CalcView.com presents video solutions of selected exercises from the text. Watch calculus instructors progress step-by-step through solutions, providing guidance to help you solve the selected exercise and others like it. Access the videos directly by scanning QR Codes®, or watch the videos at CalcView.com.

CENGAGE Learning

