

Chapter 3 section 4

3.4 | The Chain Rule

Suppose you are asked to differentiate the function

$$F(x) = \sqrt{x^2 + 1}$$

The differentiation formulas you learned in the previous sections of this chapter do not enable you to calculate $F'(x)$.

Observe that F is a composite function. In fact, if we let $y = f(u) = \sqrt{u}$ and let $u = g(x) = x^2 + 1$, then we can write $y = F(x) = f(g(x))$, that is, $F = f \circ g$. We know how to differentiate both f and g , so it would be useful to have a rule that tells us how to find the derivative of $F = f \circ g$ in terms of the derivatives of f and g .

■ The Chain Rule

It turns out that the derivative of the composite function $f \circ g$ is the product of the derivatives of f and g . This fact is one of the most important of the differentiation rules and is called the *Chain Rule*. It seems plausible if we interpret derivatives as rates of change. Regard du/dx as the rate of change of u with respect to x , dy/du as the rate of change of y with respect to u , and dy/dx as the rate of change of y with respect to x . If u changes twice as fast as x and y changes three times as fast as u , then it seems reasonable that y changes six times as fast as x , and so we expect that dy/dx is the product of dy/du and du/dx .

The Chain Rule If g is differentiable at x and f is differentiable at $g(x)$, then the composite function $F = f \circ g$ defined by $F(x) = f(g(x))$ is differentiable at x and F' is given by the product

$$\boxed{1} \quad F'(x) = f'(g(x)) \cdot g'(x)$$

In Leibniz notation, if $y = f(u)$ and $u = g(x)$ are both differentiable functions, then

$$\boxed{2} \quad \frac{dy}{dx} = \frac{dy}{du} \frac{du}{dx}$$

Formula 2 is easy to remember because if we think of dy/du and du/dx as quotients, then we could cancel du ; however, du has not been defined and du/dx should not be considered as an actual quotient.

COMMENTS ON THE PROOF OF THE CHAIN RULE Let Δu be the change in u corresponding to a change of Δx in x , that is,

$$\Delta u = g(x + \Delta x) - g(x)$$

Then the corresponding change in y is

$$\Delta y = f(u + \Delta u) - f(u)$$

It is tempting to write

$$\begin{aligned} \boxed{3} \quad \frac{dy}{dx} &= \lim_{\Delta x \rightarrow 0} \frac{\Delta y}{\Delta x} \\ &= \lim_{\Delta x \rightarrow 0} \frac{\Delta y}{\Delta u} \cdot \frac{\Delta u}{\Delta x} \\ &= \lim_{\Delta x \rightarrow 0} \frac{\Delta y}{\Delta u} \cdot \lim_{\Delta x \rightarrow 0} \frac{\Delta u}{\Delta x} \\ &= \lim_{\Delta u \rightarrow 0} \frac{\Delta y}{\Delta u} \cdot \lim_{\Delta x \rightarrow 0} \frac{\Delta u}{\Delta x} && \text{(Note that } \Delta u \rightarrow 0 \text{ as } \Delta x \rightarrow 0 \\ &&& \text{because } g \text{ is continuous.)} \\ &= \frac{dy}{du} \frac{du}{dx} \end{aligned}$$

Chapter 3 Section 4 Homework Answers

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Table of Contents Chapter 3 Section 4 Homework Answers

1. Understanding the eBook Chapter 3 Section 4 Homework Answers
 - The Rise of Digital Reading Chapter 3 Section 4 Homework Answers
 - Advantages of eBooks Over Traditional Books
2. Identifying Chapter 3 Section 4 Homework Answers
 - Exploring Different Genres
 - Considering Fiction vs. Non-Fiction
 - Determining Your Reading Goals
3. Choosing the Right eBook Platform
 - Popular eBook Platforms
 - Features to Look for in an Chapter 3 Section 4 Homework Answers
 - User-Friendly Interface

4. Exploring eBook Recommendations from Chapter 3 Section 4 Homework Answers
 - Personalized Recommendations
 - Chapter 3 Section 4 Homework Answers User Reviews and Ratings
 - Chapter 3 Section 4 Homework Answers and Bestseller Lists
5. Accessing Chapter 3 Section 4 Homework Answers Free and Paid eBooks
 - Chapter 3 Section 4 Homework Answers Public Domain eBooks
 - Chapter 3 Section 4 Homework Answers eBook Subscription Services
 - Chapter 3 Section 4 Homework Answers Budget-Friendly Options
6. Navigating Chapter 3 Section 4 Homework Answers eBook Formats
 - ePub, PDF, MOBI, and More
 - Chapter 3 Section 4 Homework Answers Compatibility with Devices
 - Chapter 3 Section 4 Homework Answers Enhanced eBook Features
7. Enhancing Your Reading Experience
 - Adjustable Fonts and Text Sizes of Chapter 3 Section 4 Homework Answers
 - Highlighting and Note-Taking Chapter 3 Section 4 Homework Answers
 - Interactive Elements Chapter 3 Section 4 Homework Answers
8. Staying Engaged with Chapter 3 Section 4 Homework Answers
 - Joining Online Reading Communities
 - Participating in Virtual Book Clubs
 - Following Authors and Publishers Chapter 3 Section 4 Homework Answers
9. Balancing eBooks and Physical Books Chapter 3 Section 4 Homework Answers
 - Benefits of a Digital Library
 - Creating a Diverse Reading Collection Chapter 3 Section 4 Homework Answers
10. Overcoming Reading Challenges
 - Dealing with Digital Eye Strain
 - Minimizing Distractions
 - Managing Screen Time
11. Cultivating a Reading Routine Chapter 3 Section 4 Homework Answers
 - Setting Reading Goals Chapter 3 Section 4 Homework Answers
 - Carving Out Dedicated Reading Time

12. Sourcing Reliable Information of Chapter 3 Section 4 Homework Answers
 - Fact-Checking eBook Content of Chapter 3 Section 4 Homework Answers
 - Distinguishing Credible Sources
13. Promoting Lifelong Learning
 - Utilizing eBooks for Skill Development
 - Exploring Educational eBooks
14. Embracing eBook Trends
 - Integration of Multimedia Elements
 - Interactive and Gamified eBooks

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