

CALCULUS 2

INTEGRAL & DIFFERENTIAL CALCULUS FOR ADVANCED STUDENTS

INTEGRATION

DEFINITIONS

Integration. The definite integral expresses the idea of adding the values of a function over a continuous interval.

Riemann sum. A regular Riemann sum of a function f defined on $[a, b]$ is approximated by a partition, which is a finite division of $[a, b]$ into subintervals, typically expressed by endpoints $x_0, x_1, x_2, \dots, x_n$ and a sampling of points, one point from each subinterval, say c_i from $[x_{i-1}, x_i]$. The associated Riemann sum is $\sum_{i=1}^n f(c_i)(x_i - x_{i-1})$.

A **regular partition** has subintervals all the same length, $x_i - x_{i-1} = \Delta x$, $x_i = a + i\Delta x$. A partition's error is the maximum subinterval length. A left sum takes the left endpoint $c_i = x_{i-1}$ of each subinterval, a right sum, the right endpoint, an upper sum (or **circumscribed sum**) takes a point c_i in each subinterval where the maximum value of f is achieved, a lower sum, the minimum value. E.g., the upper Riemann sum of $\cos x$ on $[\pi/2, \pi]$ with a regular partition of 4 intervals is the left sum where the cosine is decreasing on the interval: $\sum_{i=1}^4 \cos(\pi/2 + (i-1)\pi/4) \Delta x$.



Definite Integral. The definite integral of f from a to b may be denoted as $\int_a^b f(x) dx$ or $\int_a^b f(x)$. The limit is used to mean if some number K can be called the integral value for the following: every $\epsilon > 0$ there is a δ such that all Riemann sums on partitions of $[a, b]$ with mesh less than δ differ from K by less than ϵ . It then is said that K is the limit and is said to be integrable and the value is denoted $\int_a^b f(x) dx$ or $\int_a^b f$. The function used for notation in the integrals. The function f is called the **integrand** and the points a and b are called the **lower limit** and **upper limit** of integration, respectively. The most integral refers to the function of \int from f and dx as well as to the resulting value of \int from f and dx .

Indefinite Integral. An antiderivative of a function f is a function F whose derivative is f (not copyright for all or some domain possibly on intervals, say two antiderivatives of a function on an interval differ by a constant in consequence of the Mean Value Theorem). E.g., both $\frac{1}{2}x^2 + 4x^3$ and $\frac{1}{2}x^2 + 4x^3 + 5$ are antiderivatives of x , differing by $\frac{1}{2}x^2$. The indefinite integral of a function f , denoted $\int f(x) dx$, is an expression for the family of antiderivatives on a general (often unspecified) interval, e.g., for $x > -2$, or for $x > 0$, $\int x^2 dx = \frac{1}{3}x^3 + C$.

The constant C , which may have any real value, is the constant of integration. Computer programs, and this sheet, may omit the constant, it being understood by the knowledgeable user that the given antiderivative is just one representative of a class.

INTERPRETATIONS

Area under a curve. If f is nonnegative and continuous on $[a, b]$, then $\int_a^b f(x) dx$ gives the area between the curve and the graph. The area function, $A(x) = \int_a^x f(t) dt$ gives the area accumulated up to x . If f is negative, the integral is the negative of the area.

Average value. The average value of f over an interval $[a, b]$ may be denoted by average value $= \frac{1}{b-a} \int_a^b f(x) dx$.

A rough estimate of an integral may be made by estimating the average value, the bounding the graph and multiplying it by the length of the interval, that being the Mean Value Theorem for integrals, as the theory explains.

Continuous change. The integral of a rate of change of a quantity over a time interval gives the total change in the quantity over the time interval. E.g., if velocity is a velocity (the rate of change of position), then $\int_a^b v(t) dt$ is the approximate displacement (change in the distance) from $t=a$ until the displacement, the distance traveled given the approximate change in position over the entire time interval. In the limit of small time increments, one gets the exact total displacement: $\int_a^b v(t) dt = x(b) - x(a)$.

Integral curve. Imagine that a function f describes a slope field for each x . Plotting line segments with slope $f(x)$ at points (x, y) for various y and doing this for various x , one gets a slope field. An antiderivative of f is a function whose graph is tangent to the slope field at each point. The graph of the antiderivative is called an **integral curve** of the slope field.

Solution to Initial Value problem. The solution to the differential equation $y' = f(x)$ with initial value $y(a) = y_0$ is $y(x) = y_0 + \int_a^x f(t) dt$.

THEORY

Integration & Integration. A continuous function on a closed interval is integrable. Integrability on $[a, b]$ implies integrability on closed subintervals of $[a, b]$. Assuming f is integrable on $[a, b]$ and $[c, d]$ then all a is in $[a, b]$, then $\int_a^b f(x) dx + \int_b^c f(x) dx = \int_a^c f(x) dx$. Use this to check integral evaluations with rough estimates or antiderivatives.

Basic Integral Bounds



If f is nonnegative, then $\int_a^b f(x) dx$ is nonnegative. If f is integrable on $[a, b]$, then so is kf and $\int_a^b kf(x) dx = k \int_a^b f(x) dx$.

Fundamental theorem of calculus. One part of the theorem is used to evaluate integrals. If f is continuous on $[a, b]$ and F is an antiderivative of f on that interval, then $\int_a^b f(x) dx = F(b) - F(a)$. The other part of the theorem states that if f is continuous on $[a, b]$, then $F(x) = \int_a^x f(t) dt$ is an antiderivative of f on $[a, b]$.

A function F is said to be an antiderivative of f on $[a, b]$ if $F'(x) = f(x)$ for all x in $[a, b]$. The area under the curve is the definite integral of f over the interval $[a, b]$.

Fundamental Theorem



Antiderivatives of integrals. Functions are often defined as integrals. E.g., the "area integral function" is $A(x) = \int_a^x f(t) dt$. To differentiate such, use the second part of the Fundamental theorem.

Composition involving integrals. A function such as $\int_a^x f(t) dt$ is a composition involving $A(x) = \int_a^x f(t) dt$. To differentiate, use the chain rule and the fundamental theorem: $\frac{d}{dx} \int_a^x f(t) dt = f(x)$.

Mean value theorem for integrals. If f and g are continuous on $[a, b]$, then there is a c in $[a, b]$ such that $\int_a^b f(x)g(x) dx = f(c) \int_a^b g(x) dx$. In the case $g(x) = 1$, the average value of f is attained somewhere on the interval: $\frac{1}{b-a} \int_a^b f(x) dx = f(c)$.

MVT for Integrals



Change of variable theorem. An integral and limits of integration can be changed to make an integral easier to approach or evaluate. In effect, the "area" is essentially redistributed without changing the integral value. If f is a function with continuous derivatives and f' is continuous, then $\int_a^b f(g(x))g'(x) dx = \int_c^d f(u) du$, where u and x are points with $g(a) = c$ and $g(b) = d$. In practice, substitutions are applied, integrals are often used to compute, and that which is more often used with u , e.g., $u = \sin x$ allows the transformation $\int_a^b \sqrt{1-\sin^2 x} dx = \int_c^d \sqrt{1-u^2} du$ where u is what becomes $\int_a^b \sin x dx$ with $u = \sin x$ or $u = \cos x$ or $u = \tan x$. The formula is often used to compute, starting with $\int_a^b f(g(x))g'(x) dx = \int_c^d f(u) du$, see derivation on pg. 2.

Variable Substitution. A rigorous definition is that $\int_a^b f(x) dx = \int_c^d f(g(x))g'(x) dx$. The change of variable formula with $u = g(x)$ yields $\int_a^b f(x) dx = \int_c^d f(u) du = \int_a^b f(u) du$, showing that $\int_a^b f(x) dx = \int_c^d f(u) du$. The other elementary properties of the integral may now be derived for each defined from the definition. In this approach, as inverse functions is defined and is defined to be the second derivative of function.



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Table of Contents Calculus 2 Quickstudy Academic

1. Understanding the eBook Calculus 2 Quickstudy Academic
 - The Rise of Digital Reading Calculus 2 Quickstudy Academic
 - Advantages of eBooks Over Traditional Books
2. Identifying Calculus 2 Quickstudy Academic
 - 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 Calculus 2 Quickstudy Academic
 - User-Friendly Interface
4. Exploring eBook Recommendations from Calculus 2 Quickstudy Academic
 - Personalized Recommendations
 - Calculus 2 Quickstudy Academic User Reviews and Ratings
 - Calculus 2 Quickstudy Academic and Bestseller Lists
5. Accessing Calculus 2 Quickstudy Academic Free and Paid eBooks

- Calculus 2 Quickstudy Academic Public Domain eBooks
 - Calculus 2 Quickstudy Academic eBook Subscription Services
 - Calculus 2 Quickstudy Academic Budget-Friendly Options
6. Navigating Calculus 2 Quickstudy Academic eBook Formats
 - ePub, PDF, MOBI, and More
 - Calculus 2 Quickstudy Academic Compatibility with Devices
 - Calculus 2 Quickstudy Academic Enhanced eBook Features
 7. Enhancing Your Reading Experience
 - Adjustable Fonts and Text Sizes of Calculus 2 Quickstudy Academic
 - Highlighting and Note-Taking Calculus 2 Quickstudy Academic
 - Interactive Elements Calculus 2 Quickstudy Academic
 8. Staying Engaged with Calculus 2 Quickstudy Academic
 - Joining Online Reading Communities
 - Participating in Virtual Book Clubs
 - Following Authors and Publishers Calculus 2 Quickstudy Academic
 9. Balancing eBooks and Physical Books Calculus 2 Quickstudy Academic
 - Benefits of a Digital Library
 - Creating a Diverse Reading Collection Calculus 2 Quickstudy Academic
 10. Overcoming Reading Challenges
 - Dealing with Digital Eye Strain
 - Minimizing Distractions
 - Managing Screen Time
 11. Cultivating a Reading Routine Calculus 2 Quickstudy Academic
 - Setting Reading Goals Calculus 2 Quickstudy Academic
 - Carving Out Dedicated Reading Time
 12. Sourcing Reliable Information of Calculus 2 Quickstudy Academic
 - Fact-Checking eBook Content of Calculus 2 Quickstudy Academic
 - 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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