Algebra Cheat Sheet

Basic Properties & Facts

Arithmetic Operations

\[ ab + ac = a(b + c) \]
\[ \frac{a}{b} = \frac{ac}{bc} \]
\[ \frac{a + c}{b} = \frac{ad + bc}{bd} \]
\[ \frac{a - b}{c - d} = \frac{b - a}{d - c} \]
\[ \frac{ab + ac}{a} = b + c, \ a \neq 0 \]

Exponent Properties

\[ a^n a^m = a^{n+m} \]
\[ \left( a^n \right)^m = a^{nm} \]
\[ \left( ab\right)^n = a^n b^n \]
\[ a^{-n} = \frac{1}{a^n} \]
\[ \left( \frac{a}{b} \right)^{-n} = \frac{b^n}{a^n} \]
\[ a^{n/m} = \sqrt[ \frac{m}{n} ]{a} \]

Properties of Inequalities

If \( a < b \) then \( a + c < b + c \) and \( a - c < b - c \)

If \( a < b \) and \( c > 0 \) then \( ac < bc \) and \( \frac{a}{c} < \frac{b}{c} \)

If \( a < b \) and \( c < 0 \) then \( ac > bc \) and \( \frac{a}{c} > \frac{b}{c} \)

Properties of Absolute Value

\[ |a| = \begin{cases} a & \text{if } a \geq 0 \\ -a & \text{if } a < 0 \end{cases} \]

\[ |a| \geq 0 \]

\[ |ab| = |a||b| \]

\[ |a + b| \leq |a| + |b| \quad \text{Triangle Inequality} \]

Distance Formula

If \( P_1 = (x_1, y_1) \) and \( P_2 = (x_2, y_2) \) are two points the distance between them is

\[ d(P_1, P_2) = \sqrt{(x_2 - x_1)^2 + (y_2 - y_1)^2} \]

Complex Numbers

\[ i = \sqrt{-1} \quad i^2 = -1 \quad \sqrt{-a} = i\sqrt{a}, \ a \geq 0 \]

\[ (a + bi) + (c + di) = a + c + (b + d)i \]
\[ (a + bi) - (c + di) = a - c + (b - d)i \]
\[ (a + bi)(c + di) = ac - bd + (ad + bc)i \]
\[ (a + bi)(a - bi) = a^2 + b^2 \]

\[ |a + bi| = \sqrt{a^2 + b^2} \quad \text{Complex Modulus} \]

\[ \overline{a + bi} = a - bi \quad \text{Complex Conjugate} \]

\[ \overline{(a + bi)(a + bi)} = |a + bi|^2 \]
Logarithms and Log Properties

**Definition**

\[ y = \log_b x \] is equivalent to \[ x = b^y \]

**Example**

\[ \log_5 125 = 3 \text{ because } 5^3 = 125 \]

**Special Logarithms**

\[ \ln \text{ natural log} \]
\[ \log \text{ common log} \]

\[ e^{x} = x \text{ where } e \approx 2.718281828 \]

Logarithm Properties

\[ \log_b b = 1 \]
\[ \log_b 1 = 0 \]
\[ \log_b b^r = x \quad b^{\log_b x} = x \]
\[ \log_b (x^r) = r \log_b x \]
\[ \log_b (xy) = \log_b x + \log_b y \]
\[ \log_b \left( \frac{x}{y} \right) = \log_b x - \log_b y \]

The domain of \[ \log_b x \] is \[ x > 0 \]

**Factoring and Solving**

**Quadratic Formula**

Solve \[ ax^2 + bx + c = 0, \quad a \neq 0 \]

\[ x = \frac{-b \pm \sqrt{b^2 - 4ac}}{2a} \]

If \[ b^2 - 4ac > 0 \] - Two real unequal solns.
If \[ b^2 - 4ac = 0 \] - Repeated real solution.
If \[ b^2 - 4ac < 0 \] - Two complex solutions.

**Square Root Property**

If \[ x^2 = p \] then \[ x = \pm \sqrt{p} \]

**Absolute Value Equations/Inequalities**

If \( b \) is a positive number

\[ |p| = b \quad \Rightarrow \quad p = -b \text{ or } p = b \]
\[ |p| < b \quad \Rightarrow \quad -b < p < b \]
\[ |p| > b \quad \Rightarrow \quad p < -b \text{ or } p > b \]

**Completing the Square**

Solve \[ 2x^2 - 6x - 10 = 0 \]

(1) Divide by the coefficient of the \[ x^2 \]

\[ x^2 - 3x - 5 = 0 \]

(2) Move the constant to the other side.

\[ x^2 - 3x = 5 \]

(3) Take half the coefficient of \( x \), square it and add it to both sides

\[ x^2 - 3x + \left( -\frac{3}{2} \right)^2 = 5 + \left( -\frac{3}{2} \right)^2 = 5 + \frac{9}{4} = \frac{29}{4} \]

(4) Factor the left side

\[ \left( x - \frac{3}{2} \right)^2 = \frac{29}{4} \]

(5) Use Square Root Property

\[ x - \frac{3}{2} = \pm \frac{\sqrt{29}}{2} \]

(6) Solve for \( x \)

\[ x = \frac{3}{2} \pm \frac{\sqrt{29}}{2} \]

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Functions and Graphs

Constant Function
\[ y = a \quad \text{or} \quad f(x) = a \]
Graph is a horizontal line passing through the point \((0, a)\).

Line/Linear Function
\[ y = mx + b \quad \text{or} \quad f(x) = mx + b \]
Graph is a line with point \((0, b)\) and slope \(m\).

Slope
Slope of the line containing the two points \((x_1, y_1)\) and \((x_2, y_2)\) is
\[ m = \frac{y_2 - y_1}{x_2 - x_1} \]

Slope – intercept form
The equation of the line with slope \(m\) and y-intercept \((0, b)\) is
\[ y = mx + b \]

Point – Slope form
The equation of the line with slope \(m\) and passing through the point \((x_1, y_1)\) is
\[ y = y_1 + m(x - x_1) \]

Parabola/Quadratic Function
\[ y = a(x-h)^2 + k \quad f(x) = a(x-h)^2 + k \]
The graph is a parabola that opens up if \(a > 0\) or down if \(a < 0\) and has a vertex at \((h, k)\).

Parabola/Quadratic Function
\[ y = ax^2 + bx + c \quad f(x) = ax^2 + bx + c \]
The graph is a parabola that opens up if \(a > 0\) or down if \(a < 0\) and has a vertex at \(\left( -\frac{b}{2a}, f\left( -\frac{b}{2a} \right) \right) \).
## Common Algebraic Errors

<table>
<thead>
<tr>
<th>Error</th>
<th>Reason/Correct/Justification/Example</th>
</tr>
</thead>
<tbody>
<tr>
<td>( \frac{2}{0} \neq 0 ) and ( \frac{2}{0} \neq 2 )</td>
<td>Division by zero is undefined!</td>
</tr>
<tr>
<td>(-3^2 \neq 9)</td>
<td>(-3^2 = -9), ((−3)^2 = 9) Watch parenthesis!</td>
</tr>
<tr>
<td>((x^2)^3 \neq x^6)</td>
<td>((x^2)^3 = x^2 \cdot x^2 = x^6)</td>
</tr>
<tr>
<td>(a \neq a + \frac{a}{b} + \frac{a}{c})</td>
<td>(1 = \frac{1}{2} + \frac{1}{1} = 2)</td>
</tr>
<tr>
<td>(\frac{1}{x^2 + x^3} \neq x^{-2} + x^{-3})</td>
<td>A more complex version of the previous error.</td>
</tr>
<tr>
<td>(\frac{a + bx}{a} + bx \neq 1 + bx)</td>
<td>(\frac{a + bx}{a} = 1 + \frac{bx}{a}) Beware of incorrect canceling!</td>
</tr>
<tr>
<td>(-a(x-1) \neq -ax - a)</td>
<td>(-a(x-1) = -ax + a) Make sure you distribute the “-“!</td>
</tr>
<tr>
<td>((x+a)^2 \neq x^2 + a^2)</td>
<td>((x+a)^2 = (x+a)(x+a) = x^2 + 2ax + a^2)</td>
</tr>
<tr>
<td>(\sqrt{x^2 + a^2} \neq x + a)</td>
<td>(5 = \sqrt{25} = \sqrt{3^2 + 4^2} \neq \sqrt{3^2} + \sqrt{4^2} = 3 + 4 = 7) See previous error.</td>
</tr>
<tr>
<td>((x+a)^n \neq x^n + a^n) and (\sqrt{x+a} \neq \sqrt{x} + \sqrt{a})</td>
<td>More general versions of previous three errors.</td>
</tr>
<tr>
<td>(2(x+1)^2 \neq (2x+2)^2)</td>
<td>(2(x+1)^2 = 2(x^2 + 2x + 1) = 2x^2 + 4x + 2) Square first then distribute!</td>
</tr>
<tr>
<td>((2x+2)^2 \neq 2(x+1)^2)</td>
<td>See the previous example. You can not factor out a constant if there is a power on the parenthesis!</td>
</tr>
<tr>
<td>(\sqrt{-x^2 + a^2} \neq -\sqrt{x^2 + a^2})</td>
<td>(\sqrt{-x^2 + a^2} = \left(-x^2 + a^2\right)^{\frac{1}{2}}) Now see the previous error.</td>
</tr>
<tr>
<td>(\frac{a}{b} \neq \frac{ab}{b} + \frac{ac}{bc})</td>
<td>(\frac{a}{b} = \frac{\frac{a}{1}}{\frac{b}{c}} = \frac{\frac{a}{c}}{\frac{b}{c}} = \frac{ac}{b})</td>
</tr>
</tbody>
</table>

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Trig Cheat Sheet

Definition of the Trig Functions

Right triangle definition
For this definition we assume that
\[ 0 < \theta < \frac{\pi}{2} \] or \[ 0^\circ < \theta < 90^\circ \].

- \[ \sin \theta = \frac{\text{opposite}}{\text{hypotenuse}} \]
- \[ \cos \theta = \frac{\text{adjacent}}{\text{hypotenuse}} \]
- \[ \tan \theta = \frac{\text{opposite}}{\text{adjacent}} \]
- \[ \csc \theta = \frac{1}{\sin \theta} = \frac{\text{hypotenuse}}{\text{opposite}} \]
- \[ \sec \theta = \frac{1}{\cos \theta} = \frac{\text{hypotenuse}}{\text{adjacent}} \]
- \[ \cot \theta = \frac{1}{\tan \theta} = \frac{\text{adjacent}}{\text{opposite}} \]

Unit circle definition
For this definition \( \theta \) is any angle.

\[
\sin \theta = \frac{y}{r}, \quad \cos \theta = \frac{x}{r}, \quad \tan \theta = \frac{y}{x}, \quad \csc \theta = \frac{r}{y}, \quad \sec \theta = \frac{r}{x}, \quad \cot \theta = \frac{x}{y}
\]

Facts and Properties

Domain
The domain is all the values of \( \theta \) that can be plugged into the function.

- \( \sin \theta \), \( \theta \) can be any angle
- \( \cos \theta \), \( \theta \) can be any angle
- \( \tan \theta \), \( \theta \neq \left( n + \frac{1}{2} \right) \pi \), \( n = 0, \pm 1, \pm 2, \ldots \)
- \( \csc \theta \), \( \theta \neq n \pi \), \( n = 0, \pm 1, \pm 2, \ldots \)
- \( \sec \theta \), \( \theta \neq \left( n + \frac{1}{2} \right) \pi \), \( n = 0, \pm 1, \pm 2, \ldots \)
- \( \cot \theta \), \( \theta \neq n \pi \), \( n = 0, \pm 1, \pm 2, \ldots \)

Range
The range is all possible values to get out of the function.

- \( -1 \leq \sin \theta \leq 1 \) \( \csc \theta \geq 1 \) and \( \csc \theta \leq -1 \)
- \( -1 \leq \cos \theta \leq 1 \) \( \sec \theta \geq 1 \) and \( \sec \theta \leq -1 \)
- \( -\infty < \tan \theta < \infty \) \( -\infty < \cot \theta < \infty \)

Period
The period of a function is the number, \( T \), such that \( f(\theta + T) = f(\theta) \). So, if \( \omega \) is a fixed number and \( \theta \) is any angle we have the following periods.

- \( \sin(\omega \theta) \rightarrow T = \frac{2\pi}{\omega} \)
- \( \cos(\omega \theta) \rightarrow T = \frac{2\pi}{\omega} \)
- \( \tan(\omega \theta) \rightarrow T = \frac{\pi}{\omega} \)
- \( \csc(\omega \theta) \rightarrow T = \frac{2\pi}{\omega} \)
- \( \sec(\omega \theta) \rightarrow T = \frac{2\pi}{\omega} \)
- \( \cot(\omega \theta) \rightarrow T = \frac{\pi}{\omega} \)
Formulas and Identities

**Tangent and Cotangent Identities**
\[ \tan \theta = \frac{\sin \theta}{\cos \theta}, \quad \cot \theta = \frac{\cos \theta}{\sin \theta} \]

**Reciprocal Identities**
\[ \csc \theta = \frac{1}{\sin \theta}, \quad \sin \theta = \frac{1}{\csc \theta} \]
\[ \sec \theta = \frac{1}{\cos \theta}, \quad \cos \theta = \frac{1}{\sec \theta} \]
\[ \cot \theta = \frac{1}{\tan \theta}, \quad \tan \theta = \frac{1}{\cot \theta} \]

**Pythagorean Identities**
\[ \sin^2 \theta + \cos^2 \theta = 1 \]
\[ \tan^2 \theta + 1 = \sec^2 \theta \]
\[ 1 + \cot^2 \theta = \csc^2 \theta \]

**Even/Odd Formulas**
\[ \sin(-\theta) = -\sin \theta, \quad csc(-\theta) = -csc \theta \]
\[ \cos(-\theta) = \cos \theta, \quad sec(-\theta) = \sec \theta \]
\[ \tan(-\theta) = -\tan \theta, \quad cot(-\theta) = -\cot \theta \]

**Periodic Formulas**
If \( n \) is an integer.
\[ \sin(\theta + 2\pi n) = \sin \theta, \quad \csc(\theta + 2\pi n) = \csc \theta \]
\[ \cos(\theta + 2\pi n) = \cos \theta, \quad \sec(\theta + 2\pi n) = \sec \theta \]
\[ \tan(\theta + \pi n) = \tan \theta, \quad \cot(\theta + \pi n) = \cot \theta \]

**Double Angle Formulas**
\[ \sin(2\theta) = 2\sin \theta \cos \theta \]
\[ \cos(2\theta) = \cos^2 \theta - \sin^2 \theta \]
\[ = 2\cos^2 \theta - 1 \]
\[ = 1 - 2\sin^2 \theta \]
\[ \tan(2\theta) = \frac{2\tan \theta}{1 - \tan^2 \theta} \]

**Degrees to Radians Formulas**
If \( x \) is an angle in degrees and \( t \) is an angle in radians then
\[ \frac{\pi}{180} = \frac{t}{x} \Rightarrow t = \frac{\pi x}{180} \quad \text{and} \quad x = \frac{180t}{\pi} \]

**Half Angle Formulas**
\[ \sin^2 \frac{\theta}{2} = \frac{1}{2} \left[ 1 - \cos(\theta) \right] \]
\[ \cos^2 \frac{\theta}{2} = \frac{1}{2} \left[ 1 + \cos(\theta) \right] \]
\[ \tan^2 \frac{\theta}{2} = \frac{1 - \cos(\theta)}{1 + \cos(\theta)} \]

**Sum and Difference Formulas**
\[ \sin(\alpha \pm \beta) = \sin \alpha \cos \beta \pm \cos \alpha \sin \beta \]
\[ \cos(\alpha \pm \beta) = \cos \alpha \cos \beta \mp \sin \alpha \sin \beta \]
\[ \tan(\alpha \pm \beta) = \frac{\tan \alpha \pm \tan \beta}{1 \mp \tan \alpha \tan \beta} \]

**Product to Sum Formulas**
\[ \sin \alpha \sin \beta = \frac{1}{2} \left[ \cos(\alpha - \beta) - \cos(\alpha + \beta) \right] \]
\[ \cos \alpha \cos \beta = \frac{1}{2} \left[ \cos(\alpha - \beta) + \cos(\alpha + \beta) \right] \]
\[ \sin \alpha \cos \beta = \frac{1}{2} \left[ \sin(\alpha + \beta) + \sin(\alpha - \beta) \right] \]
\[ \cos \alpha \sin \beta = \frac{1}{2} \left[ \sin(\alpha + \beta) - \sin(\alpha - \beta) \right] \]

**Sum to Product Formulas**
\[ \sin \alpha + \sin \beta = 2 \sin \left( \frac{\alpha + \beta}{2} \right) \cos \left( \frac{\alpha - \beta}{2} \right) \]
\[ \sin \alpha - \sin \beta = 2 \cos \left( \frac{\alpha + \beta}{2} \right) \sin \left( \frac{\alpha - \beta}{2} \right) \]
\[ \cos \alpha + \cos \beta = 2 \cos \left( \frac{\alpha + \beta}{2} \right) \cos \left( \frac{\alpha - \beta}{2} \right) \]
\[ \cos \alpha - \cos \beta = -2 \sin \left( \frac{\alpha + \beta}{2} \right) \sin \left( \frac{\alpha - \beta}{2} \right) \]

**Cofunction Formulas**
\[ \sin \left( \frac{\pi}{2} - \theta \right) = \cos \theta, \quad \cos \left( \frac{\pi}{2} - \theta \right) = \sin \theta \]
\[ \csc \left( \frac{\pi}{2} - \theta \right) = \sec \theta, \quad \sec \left( \frac{\pi}{2} - \theta \right) = \csc \theta \]
\[ \tan \left( \frac{\pi}{2} - \theta \right) = \cot \theta, \quad \cot \left( \frac{\pi}{2} - \theta \right) = \tan \theta \]
For any ordered pair on the unit circle \((x, y)\) : \(\cos \theta = x\) and \(\sin \theta = y\)

**Example**

\[
\cos \left( \frac{5\pi}{3} \right) = \frac{1}{2} \quad \sin \left( \frac{5\pi}{3} \right) = -\frac{\sqrt{3}}{2}
\]

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Inverse Trig Functions

**Definition**

\[ y = \sin^{-1} x \] is equivalent to \( x = \sin y \)

\[ y = \cos^{-1} x \] is equivalent to \( x = \cos y \)

\[ y = \tan^{-1} x \] is equivalent to \( x = \tan y \)

**Inverse Properties**

\[ \cos \left( \cos^{-1} (x) \right) = x \]

\[ \sin \left( \sin^{-1} (x) \right) = x \]

\[ \tan \left( \tan^{-1} (x) \right) = x \]

\[ \cos^{-1} \left( \cos (\theta) \right) = \theta \]

\[ \sin^{-1} \left( \sin (\theta) \right) = \theta \]

\[ \tan^{-1} \left( \tan (\theta) \right) = \theta \]

**Domain and Range**

<table>
<thead>
<tr>
<th>Function</th>
<th>Domain</th>
<th>Range</th>
</tr>
</thead>
<tbody>
<tr>
<td>( y = \sin^{-1} x )</td>
<td>(-1 \leq x \leq 1)</td>
<td>(-\frac{\pi}{2} \leq y \leq \frac{\pi}{2})</td>
</tr>
<tr>
<td>( y = \cos^{-1} x )</td>
<td>(-1 \leq x \leq 1)</td>
<td>(0 \leq y \leq \pi)</td>
</tr>
<tr>
<td>( y = \tan^{-1} x )</td>
<td>(-\infty &lt; x &lt; \infty)</td>
<td>(-\frac{\pi}{2} &lt; y &lt; \frac{\pi}{2})</td>
</tr>
</tbody>
</table>

**Alternate Notation**

\( \sin^{-1} x = \arcsin x \)

\( \cos^{-1} x = \arccos x \)

\( \tan^{-1} x = \arctan x \)

---

**Law of Sines, Cosines and Tangents**

\[ \sin \alpha = \frac{\sin \beta}{b} = \frac{\sin \gamma}{c} \]

**Law of Cosines**

\[ a^2 = b^2 + c^2 - 2bc \cos \alpha \]

\[ b^2 = a^2 + c^2 - 2ac \cos \beta \]

\[ c^2 = a^2 + b^2 - 2ab \cos \gamma \]

**Mollweide’s Formula**

\[ \frac{a + b}{c} \cos \frac{1}{2} (\alpha - \beta) \]

[Diagram of triangle with sides labeled]

**Law of Tangents**

\[ \frac{a - b}{a + b} = \tan \frac{1}{2} (\alpha - \beta) \]

\[ \frac{b - c}{b + c} = \tan \frac{1}{2} (\beta - \gamma) \]

\[ \frac{a - c}{a + c} = \tan \frac{1}{2} (\alpha - \gamma) \]

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Calculus Cheat Sheet

**Limit Definitions**

**Precise Definition**: We say \( \lim_{x \to a} f(x) = L \) if for every \( \varepsilon > 0 \) there is a \( \delta > 0 \) such that whenever \( 0 < |x - a| < \delta \) then \( |f(x) - L| < \varepsilon \).

**“Working” Definition**: We say \( \lim_{x \to a} f(x) = L \) if we can make \( f(x) \) as close to \( L \) as we want by taking \( x \) sufficiently close to \( a \) (on either side of \( a \)) without letting \( x = a \).

**Right hand limit**: \( \lim_{x \to a^+} f(x) = L \). This has the same definition as the limit except it requires \( x > a \).

**Left hand limit**: \( \lim_{x \to a^-} f(x) = L \). This has the same definition as the limit except it requires \( x < a \).

**Relationship between the limit and one-sided limits**

\[
\lim_{x \to a} f(x) = L \implies \lim_{x \to a^+} f(x) = \lim_{x \to a^-} f(x) = L \quad \lim_{x \to a} f(x) = L = \lim_{x \to a^-} f(x) \impliedby \lim_{x \to a^+} f(x) = \lim_{x \to a^-} f(x) \implies \lim_{x \to a} f(x) \text{ Does Not Exist}
\]

**Properties**

Assume \( \lim_{x \to a} f(x) \) and \( \lim_{x \to a} g(x) \) both exist and \( c \) is any number then,

1. \( \lim_{x \to a} [cf(x)] = c \lim_{x \to a} f(x) \)
2. \( \lim_{x \to a} [f(x) \pm g(x)] = \lim_{x \to a} f(x) \pm \lim_{x \to a} g(x) \)
3. \( \lim_{x \to a} [f(x) g(x)] = \lim_{x \to a} f(x) \lim_{x \to a} g(x) \)
4. \( \lim_{x \to a} \left[ \frac{f(x)}{g(x)} \right] = \frac{\lim_{x \to a} f(x)}{\lim_{x \to a} g(x)} \) provided \( \lim_{x \to a} g(x) \neq 0 \)
5. \( \lim_{x \to a} [f(x)]^n = \left[ \lim_{x \to a} f(x) \right]^n \)
6. \( \lim_{x \to a} \sqrt[n]{f(x)} = \sqrt[n]{\lim_{x \to a} f(x)} \)

**Basic Limit Evaluations at \( \pm \infty \)**

<table>
<thead>
<tr>
<th>Property</th>
<th>Formula</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. ( \lim_{x \to \pm \infty} e^x = \infty ) &amp; ( \lim_{x \to -\infty} e^x = 0 )</td>
<td>5. ( n \text{ even} ) : ( \lim_{x \to \pm \infty} x^n = \infty )</td>
</tr>
<tr>
<td>2. ( \lim_{x \to \infty} \ln(x) = \infty ) &amp; ( \lim_{x \to 0^-} \ln(x) = -\infty )</td>
<td>6. ( n \text{ odd} ) : ( \lim_{x \to \infty} x^n = \infty ) &amp; ( \lim_{x \to -\infty} x^n = -\infty )</td>
</tr>
<tr>
<td>3. If ( r &gt; 0 ) then ( \lim_{x \to 0^+} \frac{b}{x^r} = 0 )</td>
<td>7. ( n \text{ even} ) : ( \lim_{x \to \pm \infty} ax^n + \cdots + bx + c = \text{sgn}(a) \infty )</td>
</tr>
<tr>
<td>4. If ( r &gt; 0 ) and ( x^r ) is real for negative ( x ) then ( \lim_{x \to -\infty} \frac{b}{x^r} = 0 )</td>
<td>8. ( n \text{ odd} ) : ( \lim_{x \to \infty} ax^n + \cdots + bx + c = \text{sgn}(a) \infty )</td>
</tr>
<tr>
<td>9. ( n \text{ odd} ) : ( \lim_{x \to -\infty} ax^n + \cdots + c x + d = -\text{sgn}(a) \infty )</td>
<td></td>
</tr>
</tbody>
</table>

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**Evaluation Techniques**

### Continuous Functions
If \( f(x) \) is continuous at \( a \) then \( \lim_{x \to a} f(x) = f(a) \)

### Continuous Functions and Composition
\( f(x) \) is continuous at \( b \) and \( \lim_{x \to a} g(x) = b \) then
\[
\lim_{x \to a} f(g(x)) = f(\lim_{x \to a} g(x)) = f(b)
\]

### Factor and Cancel
\[
\lim_{x \to 2} \frac{x^2 + 4x - 12}{x^2 - 2x} = \lim_{x \to 2} \frac{(x-2)(x+6)}{x(x-2)} = \lim_{x \to 2} \frac{x+6}{x} = \frac{8}{2} = 4
\]

### Rationalize Numerator/Denominator
\[
\lim_{x \to -9} \frac{3 - \sqrt{x}}{x^2 - 81} = \lim_{x \to -9} \frac{3 - \sqrt{x}}{x^2 - 81} \cdot \frac{3 + \sqrt{x}}{3 + \sqrt{x}} = \lim_{x \to -9} \frac{9 - x}{(x^2 - 81)(3 + \sqrt{x})} = \lim_{x \to -9} \frac{-1}{(x+9)(3 + \sqrt{x})} = \frac{-1}{18(6)} = -\frac{1}{108}
\]

### Combine Rational Expressions
\[
\lim_{h \to 0} \frac{1}{h} \left( \frac{1}{x + h} - \frac{1}{x} \right) = \lim_{h \to 0} \frac{1}{h} \left( \frac{x - (x+h)}{x(x+h)} \right)
= \lim_{h \to 0} \frac{1}{h} \left( \frac{-h}{x(x+h)} \right) = \lim_{h \to 0} -\frac{1}{h(x+h)} = -\frac{1}{x^2}
\]

### L'Hospital’s Rule
If \( \lim_{x \to a} \frac{f(x)}{g(x)} = \frac{0}{0} \) or \( \lim_{x \to a} g(x) = \pm \infty \) then,
\[
\lim_{x \to a} \frac{f(x)}{g(x)} = \lim_{x \to a} \frac{f'(x)}{g'(x)} \quad a \text{ is a number, } \pm \infty \text{ or } -\infty
\]

### Polynomials at Infinity
\( p(x) \) and \( q(x) \) are polynomials. To compute
\[
\lim_{x \to \pm \infty} \frac{p(x)}{q(x)} \text{ factor largest power of } x \text{ out of both } p(x) \text{ and } q(x) \text{ and then compute limit.}
\]
\[
\lim_{x \to -\infty} \frac{3x^2 - 4}{5x - 2x^2} = \lim_{x \to -\infty} \frac{x^2 \left(3 - \frac{4}{x^2}\right)}{x^2 \left(\frac{5}{x^2} - 2\right)} = \lim_{x \to -\infty} \frac{3 - \frac{4}{x^2}}{\frac{5}{x^2} - 2} = -\frac{3}{2}
\]

### Piecewise Function
\[
\lim_{x \to -2} g(x) \text{ where } g(x) = \begin{cases} x^2 + 5 & \text{if } x < -2 \\ 1 - 3x & \text{if } x \geq -2 \end{cases}
\]
Compute two one sided limits,
\[
\lim_{x \to -2^-} g(x) = \lim_{x \to -2} x^2 + 5 = 9
\]
\[
\lim_{x \to -2^+} g(x) = \lim_{x \to -2} 1 - 3x = 7
\]
One sided limits are different so \( \lim_{x \to -2} g(x) \) doesn’t exist. If the two one sided limits had been equal then \( \lim_{x \to -2} g(x) \) would have existed and had the same value.

### Some Continuous Functions
Partial list of continuous functions and the values of \( x \) for which they are continuous.
1. Polynomials for all \( x \).
2. Rational function, except for \( x \)'s that give division by zero.
3. \( \sqrt{x} \) (\( n \) odd) for all \( x \).
4. \( \sqrt[3]{x} \) (\( n \) even) for all \( x \geq 0 \).
5. \( e^x \) for all \( x \).
6. \( \ln x \) for \( x > 0 \).
7. \( \cos(x) \) and \( \sin(x) \) for all \( x \).
8. \( \tan(x) \) and \( \sec(x) \) provided
\[
x \neq \cdots, -\frac{3\pi}{2}, -\frac{\pi}{2}, \frac{\pi}{2}, \frac{3\pi}{2}, \cdots
\]
9. \( \cot(x) \) and \( \csc(x) \) provided
\[
x \neq \cdots, -2\pi, -\pi, 0, \pi, 2\pi, \cdots
\]

### Intermediate Value Theorem
Suppose that \( f(x) \) is continuous on \([a, b]\) and let \( M \) be any number between \( f(a) \) and \( f(b) \).
Then there exists a number \( c \) such that \( a < c < b \) and \( f(c) = M \).

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Derivatives

Definition and Notation

If \( y = f(x) \) then the derivative is defined to be

\[
f''(x) = \lim_{h \to 0} \frac{f(x + h) - f(x)}{h}.
\]

If \( y = f(x) \) then all of the following are equivalent notations for the derivative.

\[
f'(x) = \frac{dy}{dx} = \frac{df}{dx} = \frac{Df(x)}{dx} = \left. \frac{dy}{dx} \right|_{x=a} = \frac{dy}{dx}_{x=a} = Df(a)
\]

Interpretation of the Derivative

If \( y = f(x) \) then,

1. \( m = f'(a) \) is the slope of the tangent line to \( y = f(x) \) at \( x = a \) and the equation of the tangent line at \( x = a \) is given by \( y = f(a) + f'(a)(x-a) \).
2. \( f'(a) \) is the instantaneous rate of change of \( f(x) \) at \( x = a \).
3. If \( f(x) \) is the position of an object at time \( x \) then \( f'(a) \) is the velocity of the object at \( x = a \).

Basic Properties and Formulas

If \( f(x) \) and \( g(x) \) are differentiable functions (the derivative exists), \( c \) and \( n \) are any real numbers,

1. \( (cf)' = cf'(x) \)
2. \( (f \pm g)' = f'(x) \pm g'(x) \)
3. \( (fg)' = f'g + fg' \) – Product Rule
4. \( \left( \frac{f}{g} \right)' = \frac{f'g - fg'}{g^2} \) – Quotient Rule
5. \( \frac{d}{dx}(c) = 0 \)
6. \( \frac{d}{dx}(x^n) = nx^{n-1} \) – Power Rule
7. \( \frac{d}{dx}(f(g(x))) = f'(g(x))g'(x) \)

This is the Chain Rule

Common Derivatives

\[
\begin{align*}
\frac{d}{dx}(x) &= 1 \\
\frac{d}{dx}(\sin x) &= \cos x \\
\frac{d}{dx}(\cos x) &= -\sin x \\
\frac{d}{dx}(\tan x) &= \sec^2 x \\
\frac{d}{dx}(\sec x) &= \sec x \tan x \\
\frac{d}{dx}(\csc x) &= -\csc x \cot x \\
\frac{d}{dx}(\cot x) &= -\csc^2 x \\
\frac{d}{dx}(\sin^{-1} x) &= \frac{1}{\sqrt{1-x^2}} \\
\frac{d}{dx}(\cos^{-1} x) &= -\frac{1}{\sqrt{1-x^2}} \\
\frac{d}{dx}(\tan^{-1} x) &= \frac{1}{1+x^2} \\
\frac{d}{dx}(\ln x) &= \frac{1}{x}, \ x > 0 \\
\frac{d}{dx}(\ln|x|) &= \frac{1}{x}, \ x \neq 0 \\
\frac{d}{dx}(\log_a x) &= \frac{1}{x \ln a}, \ x > 0
\end{align*}
\]
Calculus Cheat Sheet

Chain Rule Variants
The chain rule applied to some specific functions.

1. \[ \frac{d}{dx} \left( f(x)^n \right) = n f(x)^{n-1} f'(x) \]
2. \[ \frac{d}{dx} \left( e^{f(x)} \right) = f'(x) e^{f(x)} \]
3. \[ \frac{d}{dx} \left( \ln[f(x)] \right) = \frac{f'(x)}{f(x)} \]
4. \[ \frac{d}{dx} \left( \sin[f(x)] \right) = f'(x) \cos[f(x)] \]
5. \[ \frac{d}{dx} \left( \cos[f(x)] \right) = -f'(x) \sin[f(x)] \]
6. \[ \frac{d}{dx} \left( \tan[f(x)] \right) = f'(x) \sec^2[f(x)] \]
7. \[ \frac{d}{dx} \left( \sec[f(x)] \right) = f'(x) \sec[f(x)] \tan[f(x)] \]
8. \[ \frac{d}{dx} \left( \tan^{-1}[f(x)] \right) = \frac{f'(x)}{1+[f(x)]^2} \]

Higher Order Derivatives
The Second Derivative is denoted as \[ f''(x) = \frac{d^2 f}{dx^2} \] and is defined as \[ f''(x) = (f'(x))^' \], i.e. the derivative of the first derivative, \( f'(x) \).

The \( n \)th Derivative is denoted as \[ f^{(n)}(x) = \frac{d^n f}{dx^n} \] and is defined as \[ f^{(n)}(x) = \left( f^{(n-1)}(x) \right)' \], i.e. the derivative of the \((n-1)\)st derivative, \( f^{(n-1)}(x) \).

Implicit Differentiation
Find \( y' \) if \( e^{2x-y} + x^3 y^2 = \sin(y) + 11x \). Remember \( y = y(x) \) here, so products/quotients of \( x \) and \( y \) will use the product/quotient rule and derivatives of \( y \) will use the chain rule. The “trick” is to differentiate as normal and every time you differentiate a \( y \) you tack on a \( y' \) (from the chain rule). After differentiating solve for \( y' \).

\[
\begin{align*}
e^{2x-y} (2 - 9y') + 3x^2 y^2 + 2x^3 y y' &= \cos(y) y' + 11 \\
2e^{2x-y} - 9y e^{2x-y} + 3x^2 y^2 + 2x^3 y y' &= \cos(y) y' + 11 \\
(2x^3 y - 9e^{2x-y} - \cos(y)) y' &= 11 - 2e^{2x-y} - 3x^2 y^2
\end{align*}
\]

\[ y' = \frac{11 - 2e^{2x-y} - 3x^2 y^2}{2x^3 y - 9e^{2x-y} - \cos(y)} \]

Increasing/Decreasing – Concave Up/Concave Down

Critical Points
\( x = c \) is a critical point of \( f(x) \) provided either

1. \( f'(c) = 0 \) or 2. \( f'(c) \) doesn’t exist.

Increasing/Decreasing
1. If \( f'(x) > 0 \) for all \( x \) in an interval \( I \) then \( f(x) \) is increasing on the interval \( I \).
2. If \( f'(x) < 0 \) for all \( x \) in an interval \( I \) then \( f(x) \) is decreasing on the interval \( I \).
3. If \( f'(x) = 0 \) for all \( x \) in an interval \( I \) then \( f(x) \) is constant on the interval \( I \).

Concave Up/Concave Down
1. If \( f''(x) > 0 \) for all \( x \) in an interval \( I \) then \( f(x) \) is concave up on the interval \( I \).
2. If \( f''(x) < 0 \) for all \( x \) in an interval \( I \) then \( f(x) \) is concave down on the interval \( I \).

Inflection Points
\( x = c \) is a inflection point of \( f(x) \) if the concavity changes at \( x = c \).
### Extrema

#### Extrema

1. \( x = c \) is an absolute maximum of \( f(x) \) if \( f(c) \geq f(x) \) for all \( x \) in the domain.
2. \( x = c \) is an absolute minimum of \( f(x) \) if \( f(c) \leq f(x) \) for all \( x \) in the domain.

#### Fermat’s Theorem

If \( f(x) \) has a relative (or local) extrema at \( x = c \), then \( x = c \) is a critical point of \( f(x) \).

#### Extreme Value Theorem

If \( f(x) \) is continuous on the closed interval \([a, b]\) then there exists numbers \( c \) and \( d \) so that,
1. \( a \leq c, d \leq b \) ,
2. \( f(c) \) is the abs. max. in \([a, b]\),
3. \( f(d) \) is the abs. min. in \([a, b]\).

#### Finding Absolute Extrema

To find the absolute extrema of the continuous function \( f(x) \) on the interval \([a, b]\) use the following process.
1. Find all critical points of \( f(x) \) in \([a, b]\).
2. Evaluate \( f(x) \) at all points found in Step 1.
3. Evaluate \( f(a) \) and \( f(b) \).
4. Identify the abs. max. (largest function value) and the abs. min. (smallest function value) from the evaluations in Steps 2 & 3.

### Relative (local) Extrema

1. \( x = c \) is a relative (or local) maximum of \( f(x) \) if \( f(c) \geq f(x) \) for all \( x \) near \( c \).
2. \( x = c \) is a relative (or local) minimum of \( f(x) \) if \( f(c) \leq f(x) \) for all \( x \) near \( c \).

#### 1st Derivative Test

If \( x = c \) is a critical point of \( f(x) \) then \( x = c \) is
1. a rel. max. of \( f(x) \) if \( f'(x) > 0 \) to the left of \( x = c \) and \( f'(x) < 0 \) to the right of \( x = c \).
2. a rel. min. of \( f(x) \) if \( f'(x) < 0 \) to the left of \( x = c \) and \( f'(x) > 0 \) to the right of \( x = c \).
3. not a relative extrema of \( f(x) \) if \( f''(x) \) is the same sign on both sides of \( x = c \).

#### 2nd Derivative Test

If \( x = c \) is a critical point of \( f(x) \) such that \( f''(c) = 0 \) then \( x = c \)
1. is a relative maximum of \( f(x) \) if \( f''(c) < 0 \).
2. is a relative minimum of \( f(x) \) if \( f''(c) > 0 \).
3. may be a relative maximum, relative minimum, or neither if \( f''(c) = 0 \).

#### Finding Relative Extrema and/or Classify Critical Points

1. Find all critical points of \( f(x) \).
2. Use the 1st derivative test or the 2nd derivative test on each critical point.

### Mean Value Theorem

If \( f(x) \) is continuous on the closed interval \([a, b]\) and differentiable on the open interval \((a, b)\) then there is a number \( a < c < b \) such that \( f'(c) = \frac{f(b) - f(a)}{b - a} \).

### Newton’s Method

If \( x_n \) is the \( n^{\text{th}} \) guess for the root/solution of \( f(x) = 0 \) then \((n+1)^{\text{st}}\) guess is \( x_{n+1} = x_n - \frac{f(x_n)}{f'(x_n)} \) provided \( f'(x_n) \) exists.
### Related Rates

Sketch picture and identify known/unknown quantities. Write down equation relating quantities and differentiate with respect to \( t \) using implicit differentiation (i.e. add on a derivative every time you differentiate a function of \( t \)). Plug in known quantities and solve for the unknown quantity.

**Ex.** A 15 foot ladder is resting against a wall. The bottom is initially 10 ft away and is being pushed towards the wall at \( \frac{1}{4} \) ft/sec. How fast is the top moving after 12 sec?

\[
\begin{align*}
\text{\( x' \)} & \text{ is negative because } x \text{ is decreasing. Using Pythagorean Theorem and differentiating,} \\
x^2 + y^2 = 15^2 & \Rightarrow 2x x' + 2y y' = 0 \\
\text{After 12 sec we have } x &= 10 - 12 \left(\frac{1}{4}\right) = 7 \text{ and} \\
\text{so } y &= \sqrt{15^2 - 7^2} = \sqrt{176} \text{. Plug in and solve for } y'. \\
7 \left(-\frac{1}{4}\right) + \sqrt{176} \cdot y' = 0 & \Rightarrow y' = \frac{7}{4\sqrt{176}} \text{ ft/sec}
\end{align*}
\]

**Ex.** Two people are 50 ft apart when one starts walking north. The angle \( \theta \) changes at 0.01 rad/min. At what rate is the distance between them changing when \( \theta = 0.5 \) rad?

\[
\begin{align*}
\text{We have } \theta' = 0.01 \text{ rad/min. and want to find } x'. \text{ We can use various trig fns but easiest is,} \\
\sec \theta = \frac{x}{50} & \Rightarrow \sec \theta \tan \theta \theta' = \frac{x'}{50} \\
\text{We know } \theta = 0.05 \text{ so plug in } \theta' \text{ and solve.} \\
\sec(0.5) \tan(0.5)(0.01) &= \frac{x'}{50} \\
x' &= 0.3112 \text{ ft/sec}
\end{align*}
\]

*Remember to have calculator in radians!*

### Optimization

Sketch picture if needed, write down equation to be optimized and constraint. Solve constraint for one of the two variables and plug into first equation. Find critical points of equation in range of variables and verify that they are min/max as needed.

**Ex.** We’re enclosing a rectangular field with 500 ft of fence material and one side of the field is a building. Determine dimensions that will maximize the enclosed area.

\[
\begin{align*}
\text{Building} \\
x \quad y
\end{align*}
\]

Maximize \( A = xy \) subject to constraint of \( x + 2y = 500 \). Solve constraint for \( x \) and plug into area.

\[
x = 500 - 2y \Rightarrow A = y(500 - 2y) = 500y - 2y^2
\]

Differentiate and find critical point(s).

\[
A' = 500 - 4y \Rightarrow y = 125
\]

By 2\(^{nd}\) deriv. test this is a rel. max. and so is the answer we’re after. Finally, find \( x \).

\[
x = 500 - 2(125) = 250
\]

The dimensions are then 250 x 125.

**Ex.** Determine point(s) on \( y = x^2 + 1 \) that are closest to (0,2).

Minimize \( f = d^2 = (x - 0)^2 + (y - 2)^2 \) and the constraint is \( y = x^2 + 1 \). Solve constraint for \( x^2 \) and plug into the function.

\[
x^2 = y - 1 \Rightarrow f = x^2 + (y - 2)^2 = y - 1 + (y - 2)^2 = y^2 - 3y + 3
\]

Differentiate and find critical point(s).

\[
f' = 2y - 3 \Rightarrow y = \frac{3}{2}
\]

By the 2\(^{nd}\) derivative test this is a rel. min. and so all we need to do is find \( x \) value(s).

\[
x^2 = \frac{3}{2} - 1 = \frac{1}{2} \Rightarrow x = \pm \frac{\sqrt{2}}{2}
\]

The 2 points are then \( \left( \frac{\sqrt{2}}{2}, \frac{3}{2} \right) \) and \( -\frac{\sqrt{2}}{2}, \frac{3}{2} \).
Integrals

Definitions

**Definite Integral:** Suppose \( f(x) \) is continuous on \([a, b]\). Divide \([a, b]\) into \( n \) subintervals of width \( \Delta x \) and choose \( x_i^* \) from each interval. Then

\[
\int_{a}^{b} f(x) \, dx = \lim_{n \to \infty} \sum_{i=1}^{n} f(x_i^*) \Delta x.
\]

**Anti-Derivative:** An anti-derivative of \( f(x) \) is a function, \( F(x) \), such that \( F'(x) = f(x) \).

**Indefinite Integral:**

\[
\int f(x) \, dx = F(x) + c
\]

where \( F(x) \) is an anti-derivative of \( f(x) \).

**Fundamental Theorem of Calculus**

**Part I:** If \( f(x) \) is continuous on \([a, b]\) then

\[
g(x) = \int_{a}^{x} f(t) \, dt
\]

is also continuous on \([a, b]\)

and \( g'(x) = \frac{d}{dx} \int_{a}^{x} f(t) \, dt = f(x) \).

**Part II:** \( f(x) \) is continuous on \([a, b]\), \( F(x) \) is an anti-derivative of \( f(x) \) (i.e. \( F'(x) = f(x) \)) then

\[
\int_{a}^{b} f(x) \, dx = F(b) - F(a).
\]

**Variants of Part I:**

\[
\int_{a}^{b} \left[ f(t) \, dt \right] = \int_{a}^{b} \left[ u'(x) f[u(x)] \right] \, dx
\]

\[
\int_{a}^{b} \left[ f(t) \, dt \right] = \int_{a}^{b} \left[ -v'(x) f[v(x)] \right] \, dx
\]

\[
\int_{a}^{b} \left[ f(t) \, dt \right] = \int_{a}^{b} \left[ u'(x) f[u(x)] - v'(x) f[v(x)] \right] \, dx
\]

**Properties**

\[
\int f(x) \pm g(x) \, dx = \int f(x) \, dx \pm \int g(x) \, dx
\]

\[
\int_{a}^{b} f(x) \, dx = \int_{a}^{b} f(x) \, dx
\]

\[
\int_{a}^{b} f(x) \, dx = \int_{a}^{b} f(x) \, dx + \int_{a}^{b} g(x) \, dx
\]

\[
\int_{a}^{b} f(x) \, dx = 0
\]

\[
\int_{a}^{b} f(x) \, dx = -\int_{b}^{a} f(x) \, dx
\]

If \( f(x) \geq g(x) \) on \( a \leq x \leq b \) then

\[
\int_{a}^{b} f(x) \, dx \geq \int_{a}^{b} g(x) \, dx
\]

If \( f(x) \geq 0 \) on \( a \leq x \leq b \) then \( \int_{a}^{b} f(x) \, dx \geq 0 \)

If \( m \leq f(x) \leq M \) on \( a \leq x \leq b \) then

\[
m(b-a) \leq \int_{a}^{b} f(x) \, dx \leq M(b-a)
\]

**Common Integrals**

\[
k \, dx = k \, x + c
\]

\[
x^n \, dx = \frac{1}{n+1} x^{n+1} + c, n \neq -1
\]

\[
x^{-1} \, dx = \int \frac{1}{x} \, dx = \ln |x| + c
\]

\[
\frac{1}{ax+b} \, dx = \frac{1}{a} \ln |ax+b| + c
\]

\[
\int u \, dx = u \ln (u) - u + c
\]

\[
e^u \, du = e^u + c
\]

\[
\cos u \, du = \sin u + c
\]

\[
\tan u \, du = \ln |\sec u| + c
\]

\[
\sec u \, du = \ln |\sec u + \tan u| + c
\]

\[
\frac{1}{a^2 + u^2} \, du = \frac{1}{a} \tan^{-1} \left( \frac{u}{a} \right) + c
\]

\[
\frac{1}{\sqrt{a^2 - u^2}} \, du = \sin^{-1} \left( \frac{u}{a} \right) + c
\]

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Calculus Cheat Sheet

Standard Integration Techniques

Note that at many schools all but the Substitution Rule tend to be taught in a Calculus II class.

**u Substitution**: The substitution \( u = g(x) \) will convert \( \int_a^b f(g(x))g'(x) \, dx = \int_{g(a)}^{g(b)} f(u) \, du \) using \( du = g'(x) \, dx \). For indefinite integrals drop the limits of integration.

Example:
\[
\int_1^2 5x^2 \cos(x^3) \, dx = \int_1^2 5x^2 \cos(x^3) \, dx = \int_1^2 \frac{5}{3} \cos(u) \, du
\]

\[
u = x^3 \Rightarrow du = 3x^2 \, dx \Rightarrow x^2 \, dx = \frac{1}{3} \, du\]
\[
x = 1 \Rightarrow u = 1^3 = 1 \quad :: \quad x = 2 \Rightarrow u = 2^3 = 8
\]

**Integration by Parts**:
\[
\int u \, dv = uv - \int v \, du \quad \text{and} \quad \int_a^b u \, dv = uv \bigg|_a^b - \int_a^b v \, du.
\]
Choose \( u \) and \( dv \) from integral and compute \( du \) by differentiating \( u \) and compute \( v \) using \( v = \int dv \).

Example:
\[
\int xe^{-x} \, dx
\]

\[
u = x \quad dv = e^{-x} \Rightarrow du = dx \quad v = -e^{-x}
\]
\[
\int xe^{-x} \, dx = -xe^{-x} + \int e^{-x} \, dx = -xe^{-x} - e^{-x} + c
\]

**Products and (some) Quotients of Trig Functions**
For \( \int \sin^n x \cos^m x \, dx \) we have the following:

1. **n odd**. Strip 1 sine out and convert rest to cosines using \( \sin^2 x = 1 - \cos^2 x \), then use the substitution \( u = \cos x \).
2. **m odd**. Strip 1 cosine out and convert rest to sines using \( \cos^2 x = 1 - \sin^2 x \), then use the substitution \( u = \sin x \).
3. **n and m both odd**. Use either 1. or 2.
4. **n and m both even**. Use double angle and/or half angle formulas to reduce the integral into a form that can be integrated.

**Trig Formulas**:
\[
\sin(2x) = 2 \sin(x) \cos(x), \quad \cos^2(x) = \frac{1}{2}(1 + \cos(2x)), \quad \sin^2(x) = \frac{1}{2}(1 - \cos(2x))
\]

Example:
\[
\int \tan^3 x \sec^3 x \, dx
\]
\[
\int \tan^3 x \sec^3 x \, dx = \int \tan^2 x \sec^4 x \tan x \sec x \, dx
\]
\[
= \int (\sec^2 x - 1) \sec^4 x \tan x \sec x \, dx
\]
\[
= \int (u^2 - 1)u^4 \, du \quad (u = \sec x)
\]
\[
= \frac{1}{5} \sec^7 x - \frac{1}{5} \sec^5 x + c
\]

Example:
\[
\int \frac{\sin^5 x \, dx}{\cos^3 x}
\]
\[
\int \frac{\sin^5 x \, dx}{\cos^3 x} = \int \sin^4 x \tan x \, dx = \int \frac{(\sin^2 x)^2 \sin x \, dx}{\cos^3 x}
\]
\[
= \int (1 - \cos^2 x)^2 \sin x \, dx \quad (u = \cos x)
\]
\[
= -\int \frac{1 - u^2}{u^3} \, du = -\int \frac{1 - 2u^2 + u^4}{u^3} \, du
\]
\[
= \frac{1}{2} \sec^2 x + 2 \ln |\cos x| - \frac{1}{2} \cos^2 x + c
\]
Trig Substitutions: If the integral contains the following root use the given substitution and formula to convert into an integral involving trig functions.

\[
\begin{align*}
\sqrt{a^2 - b^2x^2} & \Rightarrow x = \frac{a}{b} \sin \theta & \cos^2 \theta = 1 - \sin^2 \theta \\
\sqrt{b^2x^2 - a^2} & \Rightarrow x = \frac{a}{b} \sec \theta & \tan^2 \theta = \sec^2 \theta - 1 \\
\sqrt{a^2 + b^2x^2} & \Rightarrow x = \frac{a}{b} \tan \theta & \sec^2 \theta = 1 + \tan^2 \theta
\end{align*}
\]

Ex. \[
\int \frac{16}{x^2\sqrt{4-9x^2}} \, dx
\]

\[
x = \frac{2}{3} \sin \theta \quad \Rightarrow \quad dx = \frac{2}{3} \cos \theta \, d\theta
\]

\[
\sqrt{4-9x^2} = \sqrt{4-4\sin^2 \theta} = \sqrt{4 \cos^2 \theta} = 2 \cos \theta
\]

Recall \( \sqrt{x^2} = |x| \). Because we have an indefinite integral we’ll assume positive and drop absolute value bars. If we had a definite integral we’d need to compute \( \theta \)'s and remove absolute value bars based on that and,

\[
|x| = \begin{cases} 
  x & \text{if } x \geq 0 \\
  -x & \text{if } x < 0
\end{cases}
\]

In this case we have \( \sqrt{4-9x^2} = 2 \cos \theta \).

Partial Fractions: If integrating \( \int \frac{P(x)}{Q(x)} \, dx \) where the degree of \( P(x) \) is smaller than the degree of \( Q(x) \). Factor denominator as completely as possible and find the partial fraction decomposition of the rational expression. Integrate the partial fraction decomposition (P.F.D.). For each factor in the denominator we get term(s) in the decomposition according to the following table.

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<td>( ax+b )</td>
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</tr>
<tr>
<td>( ax^2+bx+c )</td>
<td>( \frac{Ax+B}{ax^2+bx+c} )</td>
<td>( (ax^2+bx+c)^k )</td>
<td>( \frac{A_1x+B_1}{ax^2+bx+c} + \ldots + \frac{A_kx+B_k}{(ax^2+bx+c)^k} )</td>
</tr>
</tbody>
</table>

Ex. \[
\int \frac{7x^2+13x}{(x-1)(x^2+4)} \, dx
\]

\[
\int \frac{7x^2+13x}{(x-1)(x^2+4)} \, dx = \int \frac{4}{x-1} + \frac{3x+16}{x^2+4} \, dx
\]

\[
= \int \frac{4}{x-1} + \frac{3x}{x^2+4} + \frac{16}{x^2+4} \, dx
\]

\[
= 4 \ln |x-1| + \frac{3}{2} \ln (x^2+4) + 8 \tan^{-1} \left( \frac{x}{2} \right)
\]

Here is partial fraction form and recombined.

An alternate method that sometimes works to find constants. Start with setting numerators equal in previous example: \( 7x^2 + 13x = A(x^2+4) + (Bx+C)(x-1) \). Chose nice values of \( x \) and plug in. For example if \( x = 1 \) we get \( 20 = 5A \) which gives \( A = 4 \). This won’t always work easily.
Applications of Integrals

Net Area : \( \int_a^b f(x) \, dx \) represents the net area between \( f(x) \) and the \( x \)-axis with area above \( x \)-axis positive and area below \( x \)-axis negative.

Area Between Curves : The general formulas for the two main cases for each are,
\[
y = f(x) \quad \Rightarrow \quad A = \int_a^b [\text{upper function}] - [\text{lower function}] \, dx \quad \& \quad x = f(y) \quad \Rightarrow \quad A = \int_c^d [\text{right function}] - [\text{left function}] \, dy
\]
If the curves intersect then the area of each portion must be found individually. Here are some sketches of a couple possible situations and formulas for a couple of possible cases.

Volumes of Revolution : The two main formulas are \( V = \int A(x) \, dx \) and \( V = \int A(y) \, dy \). Here is some general information about each method of computing and some examples.

<table>
<thead>
<tr>
<th>Rings</th>
<th>Cylinders</th>
</tr>
</thead>
<tbody>
<tr>
<td>( A = \pi \left( (\text{outer radius})^2 - (\text{inner radius})^2 \right) )</td>
<td>( A = 2\pi (\text{radius})(\text{width/height}) )</td>
</tr>
<tr>
<td>Limits : ( x/y ) of right/bot ring to ( x/y ) of left/top ring</td>
<td>Limits : ( x/y ) of inner cyl. to ( x/y ) of outer cyl.</td>
</tr>
<tr>
<td>Horz. Axis use ( f(x) ), Vert. Axis use ( f(y) ), ( g(x) ), ( A(x) ) and ( dx ).</td>
<td>Horz. Axis use ( f(y) ), Vert. Axis use ( f(x) ), ( g(y) ), ( A(y) ) and ( dy ).</td>
</tr>
<tr>
<td>( g(y), A(y) ) and ( dy ).</td>
<td>( g(x), A(x) ) and ( dx ).</td>
</tr>
</tbody>
</table>

Ex. Axis : \( y = a > 0 \) | Ex. Axis : \( y = a \leq 0 \) | Ex. Axis : \( y = a > 0 \) | Ex. Axis : \( y = a \leq 0 \) |
<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>( g(x) )</td>
<td>( f(x) )</td>
<td>( g(y) )</td>
<td>( f(y) )</td>
</tr>
<tr>
<td>outer radius : ( a - f(x) )</td>
<td>outer radius : (</td>
<td>a</td>
<td>+ g(x) )</td>
</tr>
<tr>
<td>inner radius : ( a - g(x) )</td>
<td>inner radius : (</td>
<td>a</td>
<td>+ f(x) )</td>
</tr>
</tbody>
</table>

These are only a few cases for horizontal axis of rotation. If axis of rotation is the \( x \)-axis use the \( y = a \leq 0 \) case with \( a = 0 \). For vertical axis of rotation (\( x = a > 0 \) and \( x = a \leq 0 \)) interchange \( x \) and \( y \) to get appropriate formulas.
Work: If a force of $F(x)$ moves an object in $a \leq x \leq b$, the work done is $W = \int_a^b F(x) \, dx$

Average Function Value: The average value of $f(x)$ on $a \leq x \leq b$ is $f_{\text{avg}} = \frac{1}{b-a} \int_a^b f(x) \, dx$

Arc Length Surface Area: Note that this is often a Calc II topic. The three basic formulas are,

$L = \int_a^b ds \quad SA = \int_a^b 2\pi y \, ds$ (rotate about x-axis) \quad SA = \int_a^b 2\pi x \, ds$ (rotate about y-axis)

where $ds$ is dependent upon the form of the function being worked with as follows.

$ds = \sqrt{1 + \left(\frac{dy}{dx}\right)^2} \, dx$ if $y = f(x)$, $a \leq x \leq b$

$ds = \sqrt{\left(\frac{dx}{dt}\right)^2 + \left(\frac{dy}{dt}\right)^2} \, dt$ if $x = f(t), y = g(t)$, $a \leq t \leq b$

$ds = \sqrt{1 + \left(\frac{dx}{dy}\right)^2} \, dy$ if $x = f(y)$, $a \leq y \leq b$

$ds = \sqrt{r^2 + \left(\frac{dr}{d\theta}\right)^2} \, d\theta$ if $r = f(\theta)$, $a \leq \theta \leq b$

With surface area you may have to substitute in for the $x$ or $y$ depending on your choice of $ds$ to match the differential in the $ds$. With parametric and polar you will always need to substitute.

Improper Integral
An improper integral is an integral with one or more infinite limits and/or discontinuous integrands. Integral is called convergent if the limit exists and has a finite value and divergent if the limit doesn’t exist or has infinite value. This is typically a Calc II topic.

Infinite Limit
1. $\int_a^\infty f(x) \, dx = \lim_{t \to \infty} \int_a^t f(x) \, dx$ \quad 2. $\int_{-\infty}^b f(x) \, dx = \lim_{t \to -\infty} \int_t^b f(x) \, dx$

3. $\int_{-\infty}^\infty f(x) \, dx = \int_a^c f(x) \, dx + \int_c^\infty f(x) \, dx$ provided BOTH integrals are convergent.

Discontinuous Integrand
1. Discont. at $a$: $\int_a^b f(x) \, dx = \lim_{t \to a^+} \int_t^b f(x) \, dx$ \quad 2. Discont. at $b$: $\int_a^b f(x) \, dx = \lim_{t \to b^-} \int_a^t f(x) \, dx$

3. Discontinuity at $a < c < b$: $\int_a^b f(x) \, dx = \int_a^c f(x) \, dx + \int_c^b f(x) \, dx$ provided both are convergent.

Comparison Test for Improper Integrals: If $f(x) \geq g(x) \geq 0$ on $[a, \infty)$ then,

1. If $\int_a^\infty f(x) \, dx$ conv. then $\int_a^\infty g(x) \, dx$ conv.
2. If $\int_a^\infty g(x) \, dx$ divg. then $\int_a^\infty f(x) \, dx$ divg.

Useful fact: If $a > 0$ then $\int_a^\infty \frac{1}{x^p} \, dx$ converges if $p > 1$ and diverges for $p \leq 1$.

Approximating Definite Integrals
For given integral $\int_a^b f(x) \, dx$ and a $n$ (must be even for Simpson’s Rule) define $\Delta x = \frac{b-a}{n}$ and divide $[a,b]$ into $n$ subintervals $[x_0,x_1], [x_1,x_2], \ldots, [x_{n-1},x_n]$ with $x_0 = a$ and $x_n = b$ then,

Midpoint Rule: $\int_a^b f(x) \, dx \approx \Delta x \left[ f\left(\frac{x_0+x_1}{2}\right) + f\left(\frac{x_1+x_2}{2}\right) + \ldots + f\left(\frac{x_{n-1}+x_n}{2}\right) \right]$, $x_i$ is midpoint $[x_{i-1},x_i]$

Trapezoid Rule: $\int_a^b f(x) \, dx \approx \frac{\Delta x}{2} \left[ f(x_0) + 2f(x_1) + 2f(x_2) + \ldots + 2f(x_{n-1}) + f(x_n) \right]$

Simpson’s Rule: $\int_a^b f(x) \, dx \approx \frac{\Delta x}{3} \left[ f(x_0) + 4f(x_1) + 2f(x_2) + \ldots + 2f(x_{n-2}) + 4f(x_{n-1}) + f(x_n) \right]$

Visit [http://tutorial.math.lamar.edu](http://tutorial.math.lamar.edu) for a complete set of Calculus notes.

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Common Derivatives and Integrals

**Derivatives**

**Basic Properties/Formulas/Rules**

\[
\frac{d}{dx}(cf(x)) = cf'(x), \quad c \text{ is any constant.}
\]

\[
\frac{d}{dx}(x^n) = nx^{n-1}, \quad n \text{ is any number.}
\]

\[
\frac{d}{dx}(c) = 0, \quad c \text{ is any constant.}
\]

\[
(fg)' = f'g + fg' \quad - \text{(Product Rule)}
\]

\[
\left(\frac{f}{g}\right)' = \frac{f'g - fg'}{g^2} \quad - \text{(Quotient Rule)}
\]

\[
\frac{d}{dx}(f(g(x))) = f'(g(x))g'(x) \quad - \text{(Chain Rule)}
\]

\[
\frac{d}{dx}(e^{g(x)}) = g'(x)e^{g(x)} \quad \frac{d}{dx}(\ln(g(x))) = \frac{g'(x)}{g(x)}
\]

**Common Derivatives**

**Polynomials**

\[
\frac{d}{dx}(c) = 0 \quad \frac{d}{dx}(x) = 1 \quad \frac{d}{dx}(cx) = c \quad \frac{d}{dx}(x^n) = nx^{n-1} \quad \frac{d}{dx}(cx^n) = ncx^{n-1}
\]

**Trig Functions**

\[
\frac{d}{dx}(\sin x) = \cos x \quad \frac{d}{dx}(\cos x) = -\sin x \quad \frac{d}{dx}(\tan x) = \sec^2 x
\]

\[
\frac{d}{dx}(\sec x) = \sec x \tan x \quad \frac{d}{dx}(\csc x) = -\csc x \cot x \quad \frac{d}{dx}(\cot x) = -\csc^2 x
\]

**Inverse Trig Functions**

\[
\frac{d}{dx}(\sin^{-1} x) = \frac{1}{\sqrt{1-x^2}} \quad \frac{d}{dx}(\cos^{-1} x) = -\frac{1}{\sqrt{1-x^2}} \quad \frac{d}{dx}(\tan^{-1} x) = \frac{1}{1+x^2}
\]

\[
\frac{d}{dx}(\sec^{-1} x) = \frac{1}{|x|\sqrt{x^2-1}} \quad \frac{d}{dx}(\csc^{-1} x) = -\frac{1}{|x|\sqrt{x^2-1}} \quad \frac{d}{dx}(\cot^{-1} x) = -\frac{1}{1+x^2}
\]

**Exponential/Logarithm Functions**

\[
\frac{d}{dx}(a^x) = a^x \ln(a) \quad \frac{d}{dx}(e^x) = e^x
\]

\[
\frac{d}{dx}(\ln(x)) = \frac{1}{x}, \quad x > 0 \quad \frac{d}{dx}(\ln|x|) = \frac{1}{x}, \quad x \neq 0 \quad \frac{d}{dx}(\log_a(x)) = \frac{1}{x \ln a}, \quad x > 0
\]

**Hyperbolic Trig Functions**

\[
\frac{d}{dx}(\sinh x) = \cosh x \quad \frac{d}{dx}(\cosh x) = \sinh x \quad \frac{d}{dx}(\tanh x) = \text{sech}^2 x
\]

\[
\frac{d}{dx}(\sech x) = -\operatorname{sech} x \tanh x \quad \frac{d}{dx}(\csc ch x) = -\csc ch x \operatorname{coth} x \quad \frac{d}{dx}(\coth x) = -\csc ch^2 x
\]
Integrals

Basic Properties/Formulas/Rules

\[ \int c f(x) \, dx = c \int f(x) \, dx , \text{ } c \text{ is a constant.} \]
\[ \int_a^b f(x) \, dx = F(b) - F(a) \text{ where } F(x) = \int f(x) \, dx \]
\[ \int_a^b c f(x) \, dx = c \int_a^b f(x) \, dx , \text{ } c \text{ is a constant.} \]
\[ \int_a^b f(x) \, dx = \int_c^b f(x) \, dx + \int_a^c f(x) \, dx \]
\[ \int_a^b c \, dx = c (b - a) \]

If \( f(x) \geq 0 \) on \( a \leq x \leq b \) then \( \int_a^b f(x) \, dx \geq 0 \)

If \( f(x) \geq g(x) \) on \( a \leq x \leq b \) then \( \int_a^b f(x) \, dx \geq \int_a^b g(x) \, dx \)

Common Integrals

Polynomials

\[ \int dx = x + c \]
\[ \int k \, dx = k x + c \]
\[ \int x^n \, dx = \frac{1}{n+1} x^{n+1} + c , \text{ } n \neq -1 \]
\[ \int \frac{1}{x} \, dx = \ln |x| + c \]
\[ \int x^{-n} \, dx = \frac{1}{-n+1} x^{-n+1} + c , \text{ } n \neq 1 \]
\[ \int \frac{1}{ax+b} \, dx = \frac{1}{a} \ln |ax+b| + c \]
\[ \int x^q \, dx = \frac{1}{q+1} x^{q+1} + c = \frac{q}{p+q} x^{q+1} + c \]

Trig Functions

\[ \int \cos u \, du = \sin u + c \]
\[ \int \sin u \, du = -\cos u + c \]
\[ \int \sec^2 u \, du = \tan u + c \]
\[ \int \sec u \tan u \, du = \sec u + c \]
\[ \int \csc u \csc u \, du = -\csc u + c \]
\[ \int \csc u \cot u \, du = -\csc u + c \]
\[ \int \tan u \, du = \ln |\sec u| + c \]
\[ \int \cot u \, du = \ln |\sin u| + c \]
\[ \int \sec u + \tan u \, du = \ln |\sec u + \tan u| + c \]
\[ \int \sec^3 u \, du = \frac{1}{2} \left( \sec u \tan u + \ln |\sec u + \tan u| \right) + c \]
\[ \int \csc u - \cot u \, du = \ln |\csc u - \cot u| + c \]
\[ \int \csc^3 u \, du = \frac{1}{2} \left( -\csc u \cot u + \ln |\csc u - \cot u| \right) + c \]

Exponential/Logarithm Functions

\[ \int e^u \, du = e^u + c \]
\[ \int a^u \, du = \frac{a^u}{\ln a} + c \]
\[ \int \ln u \, du = u \ln (u) - u + c \]
\[ \int e^{au} \sin (bu) \, du = \frac{e^{au}}{a^2 + b^2} \left( a \sin (bu) - b \cos (bu) \right) + c \]
\[ \int e^{au} \cos (bu) \, du = \frac{e^{au}}{a^2 + b^2} \left( a \cos (bu) + b \sin (bu) \right) + c \]
\[ \int \frac{1}{u \ln u} \, du = \ln |\ln u| + c \]
Inverse Trig Functions
\[
\int \frac{1}{\sqrt{a^2-u^2}} \, du = \sin^{-1} \left( \frac{u}{a} \right) + c \\
\int \frac{1}{a^2+u^2} \, du = \frac{1}{a} \tan^{-1} \left( \frac{u}{a} \right) + c \\
\int \frac{1}{u\sqrt{u^2-a^2}} \, du = \frac{1}{a} \sec^{-1} \left( \frac{u}{a} \right) + c
\]
\[
\int \sin^{-1} u \, du = u \sin^{-1} u + \sqrt{1-u^2} + c \\
\int \tan^{-1} u \, du = u \tan^{-1} u - \frac{1}{2} \ln(1+u^2) + c \\
\int \cos^{-1} u \, du = u \cos^{-1} u - \sqrt{1-u^2} + c
\]

Hyperbolic Trig Functions
\[
\int \sinh u \, du = \cosh u + c \\
\int \cosh u \, du = \sinh u + c \\
\int \text{sech}^2 u \, du = \tanh u + c \\
\int \text{sech} \tanh u \, du = -\text{sech} u + c \\
\int \text{csch} \coth u \, du = -\text{csch} u + c \\
\int \text{sech} u \, du = \ln |\cosh u| + c \\
\int \text{sech} u \, du = \tanh^{-1} |\sinh u| + c
\]

Miscellaneous
\[
\int \frac{1}{a^2-u^2} \, du = \frac{1}{2a} \ln \left| \frac{u+a}{u-a} \right| + c \\
\int \frac{1}{u^2-a^2} \, du = \frac{1}{2a} \ln \left| \frac{u-a}{u+a} \right| + c \\
\int \sqrt{a^2+u^2} \, du = \frac{u}{2} \sqrt{a^2+u^2} + \frac{a^2}{2} \ln |u+\sqrt{a^2+u^2}| + c \\
\int \sqrt{u^2-a^2} \, du = \frac{u}{2} \sqrt{u^2-a^2} - \frac{a^2}{2} \ln |u+\sqrt{u^2-a^2}| + c \\
\int \sqrt{a^2-u^2} \, du = \frac{u}{2} \sqrt{a^2-u^2} + \frac{a^2}{2} \sin^{-1} \left( \frac{u}{a} \right) + c \\
\int \sqrt{2au-u^2} \, du = \frac{u-a}{2} \sqrt{2au-u^2} + \frac{a^2}{2} \cos^{-1} \left( \frac{a-u}{a} \right) + c
\]

Standard Integration Techniques
Note that all but the first one of these tend to be taught in a Calculus II class.

\textbf{u Substitution}
Given \( \int_a^b f(g(x))g'(x) \, dx \) then the substitution \( u = g(x) \) will convert this into the integral, \( \int_a^b f(g(x))g'(x) \, dx = \int_{g(a)}^{g(b)} f(u) \, du \).

\textbf{Integration by Parts}
The standard formulas for integration by parts are,
\[
\int u \, dv = uv - \int v \, du \\
\int_a^b u \, dv = uv \bigg|_a^b - \int_a^b v \, du
\]
Choose \( u \) and \( dv \) and then compute \( du \) by differentiating \( u \) and compute \( v \) by using the fact that \( v = \int dv \).
Trig Substitutions
If the integral contains the following root use the given substitution and formula.
\[
\sqrt{a^2 - b^2x^2} \quad \Rightarrow \quad x = \frac{a}{b} \sin \theta \quad \text{and} \quad \cos^2 \theta = 1 - \sin^2 \theta
\]
\[
\sqrt{b^2x^2 - a^2} \quad \Rightarrow \quad x = \frac{a}{b} \sec \theta \quad \text{and} \quad \tan^2 \theta = \sec^2 \theta - 1
\]
\[
\sqrt{a^2 + b^2x^2} \quad \Rightarrow \quad x = \frac{a}{b} \tan \theta \quad \text{and} \quad \sec^2 \theta = 1 + \tan^2 \theta
\]

Partial Fractions
If integrating \( \int \frac{P(x)}{Q(x)} \, dx \) where the degree (largest exponent) of \( P(x) \) is smaller than the degree of \( Q(x) \) then factor the denominator as completely as possible and find the partial fraction decomposition of the rational expression. Integrate the partial fraction decomposition (P.F.D.). For each factor in the denominator we get term(s) in the decomposition according to the following table.

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</thead>
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<td>( ax + b )</td>
<td>( \frac{A}{ax + b} )</td>
<td>( (ax + b)^k )</td>
<td>( \frac{A_1}{ax + b} + \frac{A_2}{(ax + b)^2} + \cdots + \frac{A_k}{(ax + b)^k} )</td>
</tr>
<tr>
<td>( ax^2 + bx + c )</td>
<td>( \frac{Ax + B}{ax^2 + bx + c} )</td>
<td>( (ax^2 + bx + c)^k )</td>
<td>( \frac{A_1x + B_1}{ax^2 + bx + c} + \cdots + \frac{A_kx + B_k}{(ax^2 + bx + c)^k} )</td>
</tr>
</tbody>
</table>

Products and (some) Quotients of Trig Functions
\[
\int \sin^n x \cos^m x \, dx
\]

1. If \( n \) is odd. Strip one sine out and convert the remaining sines to cosines using \( \sin^2 x = 1 - \cos^2 x \), then use the substitution \( u = \cos x \)
2. If \( m \) is odd. Strip one cosine out and convert the remaining cosines to sines using \( \cos^2 x = 1 - \sin^2 x \), then use the substitution \( u = \sin x \)
3. If \( n \) and \( m \) are both odd. Use either 1. or 2.
4. If \( n \) and \( m \) are both even. Use double angle formula for sine and/or half angle formulas to reduce the integral into a form that can be integrated.

\[
\int \tan^n x \sec^m x \, dx
\]

1. If \( n \) is odd. Strip one tangent and one secant out and convert the remaining tangents to secants using \( \tan^2 x = \sec^2 x - 1 \), then use the substitution \( u = \sec x \)
2. If \( m \) is even. Strip two secants out and convert the remaining secants to tangents using \( \sec^2 x = 1 + \tan^2 x \), then use the substitution \( u = \tan x \)
3. If \( n \) is odd and \( m \) is even. Use either 1. or 2.
4. If \( n \) is even and \( m \) is odd. Each integral will be dealt with differently.

Convert Example: \( \cos^6 x = \left( \cos^2 x \right)^3 = \left( 1 - \sin^2 x \right)^3 \)
### Table of Laplace Transforms

<table>
<thead>
<tr>
<th>( f(t) = \mathcal{L}^{-1}{F(s)} )</th>
<th>( F(s) = \mathcal{L}{f(t)} )</th>
<th>( f(t) = \mathcal{L}^{-1}{F(s)} )</th>
<th>( F(s) = \mathcal{L}{f(t)} )</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>( \frac{1}{s} )</td>
<td>2. ( e^{at} )</td>
<td>( \frac{1}{s-a} )</td>
</tr>
<tr>
<td>3. ( t^n ), ( n = 1, 2, 3, \ldots )</td>
<td>( \frac{n!}{s^{n+1}} )</td>
<td>4. ( t^p ), ( p &gt; -1 )</td>
<td>( \Gamma(p+1) \frac{1}{s^{p+1}} )</td>
</tr>
<tr>
<td>5. ( \sqrt{t} )</td>
<td>( \frac{\sqrt{\pi}}{2s^{\frac{3}{2}}} )</td>
<td>6. ( t^{n-\frac{1}{2}} ), ( n = 1, 2, 3, \ldots )</td>
<td>( \frac{1 \cdot 3 \cdot 5 \cdots (2n-1) \sqrt{\pi}}{2^n s^{n+\frac{1}{2}}} )</td>
</tr>
<tr>
<td>7. ( \sin(at) )</td>
<td>( \frac{a}{s^2 + a^2} )</td>
<td>8. ( \cos(at) )</td>
<td>( \frac{s}{s^2 + a^2} )</td>
</tr>
<tr>
<td>9. ( t\sin(at) )</td>
<td>( \frac{2as}{(s^2 + a^2)^{\frac{3}{2}}} )</td>
<td>10. ( t\cos(at) )</td>
<td>( \frac{s}{s^2 - a^2} )</td>
</tr>
<tr>
<td>11. ( \sin(at) - at\cos(at) )</td>
<td>( \frac{2a^3}{(s^2 + a^2)^{\frac{5}{2}}} - \frac{s(s^2 + a^2)}{(s^2 - a^2)} )</td>
<td>12. ( \sin(at) + at\cos(at) )</td>
<td>( \frac{2as^2}{(s^2 + a^2)^{\frac{5}{2}}} )</td>
</tr>
<tr>
<td>13. ( \cos(at) - at\sin(at) )</td>
<td>( \frac{s(s^2 + 3a^2)}{(s^2 + a^2)^2} )</td>
<td>14. ( \cos(at) + at\sin(at) )</td>
<td>( \frac{1}{(s^2 + a^2)^{\frac{3}{2}}} )</td>
</tr>
<tr>
<td>15. ( \sin(at + b) )</td>
<td>( \frac{s\sin(b) + a\cos(b)}{s^2 + a^2} )</td>
<td>16. ( \cos(at + b) )</td>
<td>( \frac{s\cos(b) - a\sin(b)}{s^2 + a^2} )</td>
</tr>
<tr>
<td>17. ( \sinh(at) )</td>
<td>( \frac{a}{s^2 - a^2} )</td>
<td>18. ( \cosh(at) )</td>
<td>( \frac{s}{s^2 - a^2} )</td>
</tr>
<tr>
<td>19. ( e^{at}\sin(bt) )</td>
<td>( \frac{b}{(s-a)^2 + b^2} )</td>
<td>20. ( e^{at}\cos(bt) )</td>
<td>( \frac{1}{(s-a)^2 + b^2} )</td>
</tr>
<tr>
<td>21. ( e^{at}\sinh(bt) )</td>
<td>( \frac{b}{(s-a)^2 - b^2} )</td>
<td>22. ( e^{at}\cosh(bt) )</td>
<td>( \frac{s-a}{(s-a)^2 - b^2} )</td>
</tr>
<tr>
<td>23. ( t^ne^{at} ), ( n = 1, 2, 3, \ldots )</td>
<td>( \frac{n!}{(s-a)^{n+1}} )</td>
<td>24. ( f(ct) )</td>
<td>( \frac{1}{c} F\left(\frac{s}{c}\right) )</td>
</tr>
<tr>
<td>25. ( u_c(t) = u(t-c) )</td>
<td>( \frac{e^{-cs}}{s} )</td>
<td>26. ( \delta(t-c) )</td>
<td>( e^{-cs} )</td>
</tr>
<tr>
<td>27. ( u_c(t)f(t-c) )</td>
<td>( e^{-cs}F(s) )</td>
<td>28. ( u_c(t)g(t) )</td>
<td>( e^{-cs}G\left(t+\frac{c}{s}\right) )</td>
</tr>
<tr>
<td>29. ( e^{at}F(t) )</td>
<td>( F(s-c) )</td>
<td>30. ( t^nf(t) ), ( n = 1, 2, 3, \ldots )</td>
<td>( (-1)^n F^{(n)}(s) )</td>
</tr>
<tr>
<td>31. ( \frac{1}{t}f(t) )</td>
<td>( \int_{s}^{\infty} F(u)du )</td>
<td>32. ( \int_{0}^{t} f(v)dv )</td>
<td>( \frac{F(s)}{s} )</td>
</tr>
<tr>
<td>33. ( \int_{0}^{t} f(t-\tau)g(\tau)d\tau )</td>
<td>( F(s)G(s) )</td>
<td>34. ( f(t+T) = f(t) )</td>
<td>( \int_{0}^{T} e^{-st}f(t)dt )</td>
</tr>
<tr>
<td>35. ( f'(t) )</td>
<td>( sF(s) - f(0) )</td>
<td>36. ( f^{(n)}(t) )</td>
<td>( s^2F(s) - sf(0) - f'(0) )</td>
</tr>
<tr>
<td>37. ( f^{(n)}(t) )</td>
<td>( s^nF(s) - s^{n-1}f(0) - s^{n-2}f'(0) - \cdots - sf^{(n-2)}(0) - f^{(n-1)}(0) )</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
Table Notes

1. This list is not inclusive and only contains some of the more commonly used Laplace transforms and formulas.

2. Recall the definition of hyperbolic trig functions.
   \[
   \cosh(t) = \frac{e^t + e^{-t}}{2} \quad \sinh(t) = \frac{e^t - e^{-t}}{2}
   \]

3. Be careful when using “normal” trig function vs. hyperbolic trig functions. The only difference in the formulas is the “+ a^2” for the “normal” trig functions becomes a “- a^2” for the hyperbolic trig functions!

4. Formula #4 uses the Gamma function which is defined as
   \[
   \Gamma(t) = \int_0^\infty e^{-x}x^{t-1} \, dx
   \]
   If \( n \) is a positive integer then,
   \[
   \Gamma(n+1) = n!
   \]
   The Gamma function is an extension of the normal factorial function. Here are a couple of quick facts for the Gamma function
   \[
   \Gamma(p+1) = p\Gamma(p)
   \]
   \[
   p(p+1)(p+2)\cdots(p+n-1) = \frac{\Gamma(p+n)}{\Gamma(p)}
   \]
   \[
   \Gamma\left(\frac{1}{2}\right) = \sqrt{\pi}
   \]