Squeeze theorem practice problems with answers

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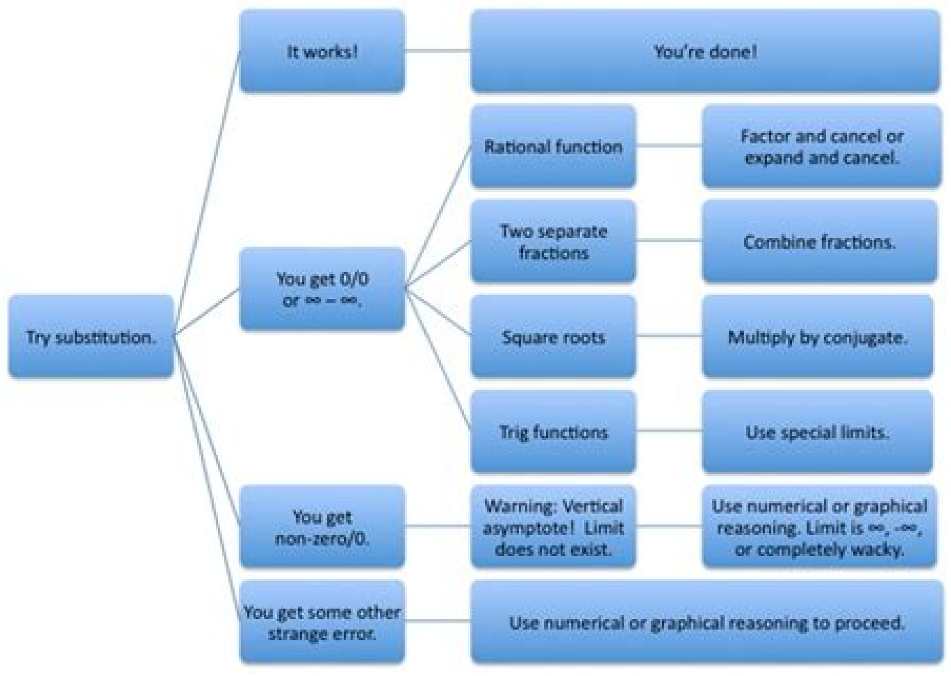

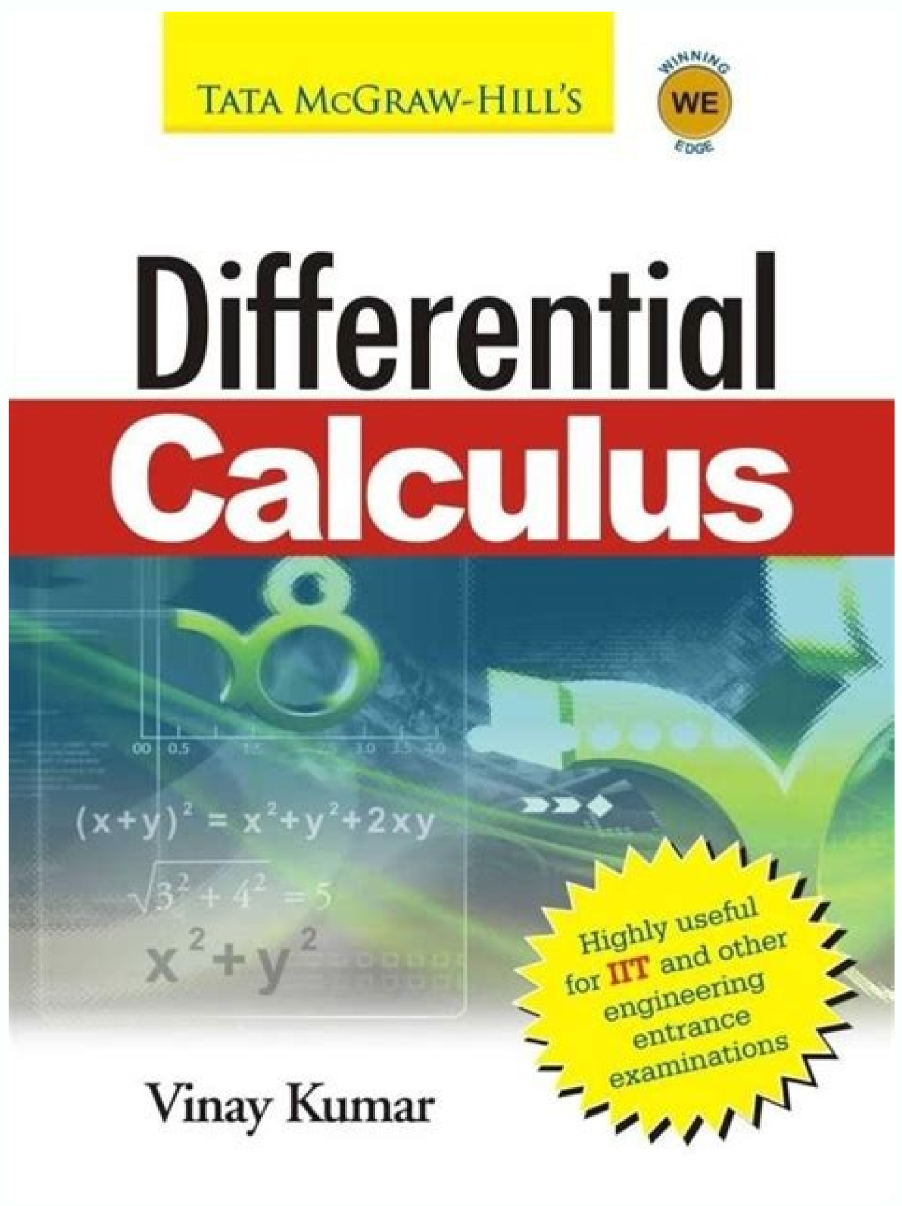

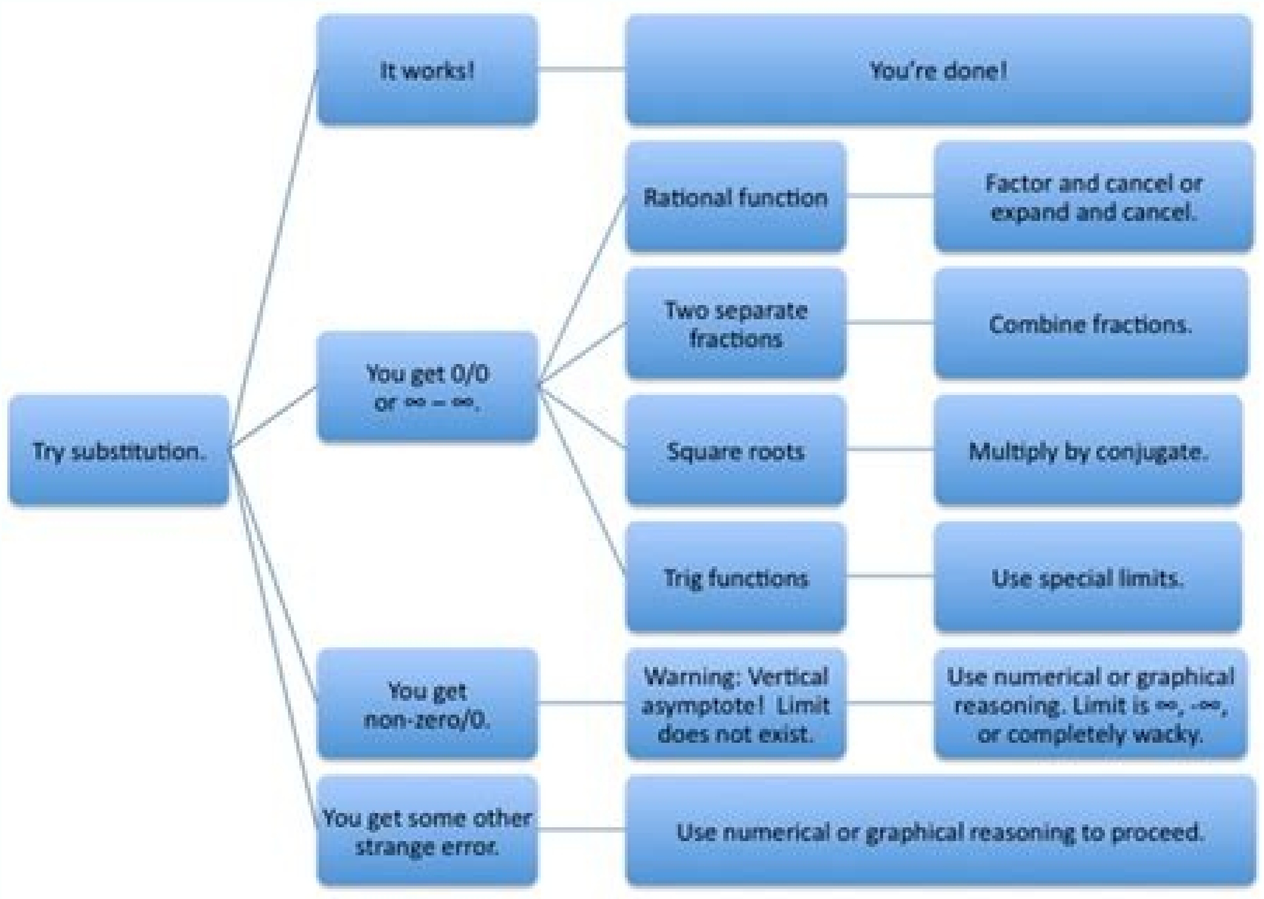

Squeeze theorem practice worksheet. Squeeze theorem problems and solutions pdf. Squeeze theorem practice problems.

In order to continue enjoying our site, we ask that you confirm your identity as a human. Thank you very much for your cooperation. Squeezing a function between functions The squeeze theorem is another way to solve for tricky limits. It works by finding two functions, f(x) and g(x), that are, for every x in their domains, greater than and less than the target function, h(x), respectively. If f(x) and g(x) have the same limit at some value of interest, say x0, then so must h(x). More precisely, the theorem says We seek $$\lim_{x \to x_o} \, h(x).$$ Let $f(x) \gt h(x)$ for all x in the domains of f(x) and h(x), and let $g(x) \lt h(x)$ for all x in the domains of g(x) and h(x). Then if $$\lim_{x \to x_o} \, f(x) = L \: \: \color{#E90F89}{\text{and}} \: \: \lim_{x \to x_o} \, g(x) = L,$$ then $$\lim_{x \to x_o} \, h(x) = L$$ because it is "squeezed" between the two functions with known limits. Example 1: $\lim_{x \to 0} \, x^2 sin \left(\frac{1}{x} \right)$ this is a difficult limit to find, but the squeeze theorem makes it easy. First, consider that $$-1 \lt sin \left(\frac{1}{x} \right) \lt 1$$ for all x. Now because $x^2 \ge 0,$ we can multiply everything by x^2 to obtain $$-x^2 \lt x^2 \, sin \left(\frac{1}{x} \right) \lt x^2$$ This is our recipe for the squeeze theorem, illustrated in the figure. For all x, the function is less than $y = x^2$ and greater than $y = -x^2,$ which both have a value of zero at x = 0, therefore the value of our function at x = 0 is zero. We can also use the squeeze theorem to prove the trigonometric limit $\lim_{x\to 0} \frac{sin(x)}{x} = 1.$ Proving this limit using the squeeze theorem involves drawing a sector of the unit circle and two triangles related to it. The areas of the triangle can be placed in order to form an inequality, which can then be manipulated into the desired squeeze theorem statment. It begins with this sector. Now the area of a sector is found by taking its proportion to the area and angle (radians) of a full circle: $$\frac{A}{\pi r^2} = \frac{x}{2 \pi}$$ which can be rearranged to give $$A = \frac{x r^2}{2} \: \rightarrow \: = \frac{x}{2},$$ where in the last step, we realize that $r = 1$ for the unit circle. Now our second triangle, the smallest of the three, is Δ ABE, shown here: The height and width of this triangle are sin(x) and 1, respectively, giving an area of $$a = \frac{1}{2} sin(x) \cdot 1$$ The largest triangle, ΔADE, is shown here The tangent of angle x is the length of the opposite side divided by the adjacent, which has length 1, so the opposite side has length $tan(x).$ Thus the area of the largest triangle is $$a = \frac{1}{2} tan(x) \cdot 1.$$ Now we can place these areas in order using inequalities: $$\frac{1}{2} sin(x) \le \frac{x}{2} \le \frac{1}{2} tan(x)$$ Multiplication by 2 and conversion of tan(x) to sin(x)/cos(x) gives $$sin(x) \le x \le \frac{sin(x)}{cos(x)}$$ Taking the reciprocal (and remembering to switch the inequalities) gives $$\frac{1}{sin(x)} \ge \frac{1}{x} \ge \frac{cos(x)}{sin(x)}$$ Multiplication through by $sin(x)$ gives $$1 \ge \frac{sin(x)}{x} \ge cos(x)$$ Now taking the limit as x → 0 squeezes the center term between 1 and 1, which requires it to also converge to a value of 1. Use the squeeze theorem to find the limit $\lim_{x \to \infty} \frac{cos(x)}{x - 1}.$ Solution: To begin, note that $$-1 \le cos(x) \le 1$$ That is, the cosine function oscillates between -1 and 1. Now divide all of these terms by $(x - 1)$: $$\frac{-1}{x - 1} \le \frac{cos(x)}{x - 1} \le \frac{1}{x - 1}$$ The middle term contains the expression for which we seek the limit, and the outer limits are: $$\lim_{x \to \infty} \frac{-1}{x - 1} \: = \: \lim_{x \to \infty} \frac{1}{x - 1} = 0.$$ So $\lim_{x \to \infty} \frac{cos(x)}{x - 1} = 0$ by the squeeze theorem. Here is a graph of the three functions, just so you can get an idea of what's going on. Use the squeeze theorem to find the limit $\lim_{x \to 0} x^2 \left[1 + sin \left(\frac{1}{x} \right)\right].$ Solution: We can begin this limit much as in example 3 above, by noting that the sine function oscillates between -1 and 1: $$-1 \le sin\left(\frac{1}{x} \right) \le 1$$ Now add 1 to all three parts of the inequality to get $$0 \le 1 + sin \left(\frac{1}{x} \right) \le 2$$ One thing we know already is that $1 + sin \left(\frac{1}{x} \right)$ is bounded between 1 and 2, so multiplication by x2, with our limit as x → 0 should also be bounded. In other words, our squeeze-theorem attempt should work. Multiplication of each element of the inequality by x2 gives $$0 \le x^2 \left[1 + sin \left(\frac{1}{x} \right) \right] \le 2x^2$$ The outer limits are both zero, so the limit of interest is squeezed between zero and zero, so it, too, is zero. Here is a graph of the three functions in the neighborhood of x = 0, showing that the function (black) is squeezed between $y = 0$ and $y = 2x^2.$ Find the limits using the squeeze theorem. 1. $$\lim_{a\to \infty} \; \frac{sin(x)}{a}$$ Hint: begin with $-1 \le sin(x) \le 1.$ Solution We begin with $$-1 \le sin(x) \le 1,$$ then divide all three components of the inequality by a: $$\frac{-1}{a} \le \frac{sin(x)}{a} \le \frac{1}{a}$$ Now the outer limits are both zero, $$\lim_{x \to \infty} \, \frac{-1}{a} = \lim_{x \to \infty} \, \frac{1}{a} = 0,$$ so the limit = 0. 2. $$\lim_{x\to 1} \; (x^2 + x - 2) \cdot cos \left(\frac{1}{x - 1} \right)$$ Hint: begin with $-1 \le cos \left(\frac{1}{x - 1} \right) \le 1$ Solution We begin with the inequality $$-1 \le cos \left(\frac{1}{1-x} \right) \le 1$$ Now multiplying both sides by $(x^2 + x - 2)$ gives $$ \begin{align} -x^2 &- x + 2 \le (x^2 + x - 2) \\[5pt] &\cdot cos \left(\frac{1}{1-x} \right) \le x^2 + x - 2 \end{align}$$ Now the outer limits evaluate to zero, so the interior limit is squeezed between 0 and 0, so $$\lim_{x \to 1} \, (x^2 + x - 2) \cdot cos \left(\frac{1}{1 - x} \right) = 0$$ Here's a graph of the functions. 3. $$\lim_{x\to 0} \; x^2 \, sin \left(\frac{2 \pi}{x} \right)$$ Hint: begin with $-1 \le sin \left(\frac{2\pi}{x} \right) \le 1$ Solution Begin with $$-1 \le sin \left(\frac{2 \pi}{x} \right) \le 1$$ Now multiply by x2 $$-x^2 \le x^2 \cdot sin \left(\frac{2 \pi}{x} \right) \le x^2$$ The outer limits both evaluate to zero, so the limit is zero. $$\lim_{x \to 0} \, x^2 \cdot sin \left(\frac{2 \pi}{x} \right) = 0$$ Here is a graph of the three functions. 4. $$\lim_{x\to 0} \, x^2 sin \left(\frac{3}{x} \right) + 2$$ Solution We begin with the inequality $$-1 \le sin \left(\frac{3}{x} \right) \le 1$$ Now multiply through by x2: $$-x^2 \le x^2 \cdot sin \left(\frac{3}{x} \right) \le x^2$$ Then add 2 to all terms, $$-x^2 + 2 \le x^2 \cdot sin \left(\frac{3}{x} \right) + 2 \le x^2 + 2$$ Now both of the outer limits evaluate to 2, so the limit is $$\lim_{x \to 0} \, x^2 \, sin \left(\frac{3}{x} \right) + 2$$ Here is a graph of the three functions showing the squeezing: 5. $$\lim_{x\to 0} x \cdot sin(x)$$ Solution Start with the inequality $$-1 \le sin(x) \le 1$$ Then multiply through by x: $$-x \le sin(x) \le x$$ The outer limits are both zero, so by squeezing, the innner limit is $$\lim_{x \to 0} \, x \cdot sin(x) = 0$$ Here is a graph of the function and the squeezing functions: 6. $$\lim_{x\to 0} \; x^2 \, cos \left(\frac{1}{x^2} \right)$$ Solution Start with the inequality $$-1 \le cos \left(\frac{1}{x^2} \right) \le 1$$ Now multiply through by x2 to get $$-x^2 \le x^2 \cdot cos \left(\frac{1}{x^2} \right) \le x^2$$ Now the outer limits both evaluate to zero, so the inner limit is $$\lim_{x \to 0} \, x^2 \, cos \left(\frac{1}{x^2} \right) = 0$$ Here is a graph of the functions. The squeeze theorem is used to evaluate a kind of limits. This is also known as the sandwich theorem. To evaluate a limit lim x → a f(x), we usually substitute x = a into f(x) and if that leads to an indeterminate form, then we apply some algebraic methods. But neither of them may work in evaluating some kind of limits such as lim x → ∞ (sin x / x). The squeeze theorem helps in this regard. Let us see what does squeeze theorem states, how to prove it, and how to apply it along with various examples. What is Squeeze Theorem? The squeeze theorem (also known as sandwich theorem) states that if a function f(x) lies between two functions g(x) and h(x) and the limits of each of g(x) and h(x) at a particular point are equal (to L), then the limit of f(x) at that point is also equal to L. This looks something like what we know already in algebra. If a ≤ b ≤ c and a = c then b is also equal to c. The squeeze theorem says that this rule applies to limits as well. Squeeze Theorem Statement We define the squeeze theorem mathematically as follows: "Let f(x), g(x), and h(x) are three functions that are defined over an interval I such that g(x) ≤ f(x) ≤ h(x) and suppose lim x → a g(x) = lim x → a h(x) = L, then lim x → a f(x) = L". Here: The function f lies between g and h and hence they are lower and upper bounds of f respectively. 'a' doesn't necessarily need to be within I. This theorem looks so obvious given the following explanation. Since f(x) lies between g(x) and h(x), the curve of f(x) should lie between the curves of g(x) and h(x) graphically. Also, when both g(x) and h(x) tend to L as x → a, then f(x) cannot escape from having the same limit as L when x → a. This is because f(x) lies between the curves of g(x) and h(x). It can be understood from the following figure. Squeeze Theorem Proof We have already seen the proof of the squeeze theorem graphically. But we are going to prove it mathematically using the definition of limits. Assume that g(x) ≤ f(x) ≤ h(x) and lim x → a g(x) = lim x → a h(x) = L. By the definition of limits: lim x → a g(x) = L means that ∀ ∈ > 0, ∃ δ1 > 0 such that |x - a| < δ1 ⇒ |g(x) - L| < ∈ This gives |x - a| < δ1 ⇒ -∈ < g(x) - L < ∈... (1) lim x → a h(x) = L means that ∀ ∈ > 0, ∃ δ2 > 0 such that |x - a| < δ2 ⇒ |h(x) - L| < ∈ This gives |x - a| < δ2 ⇒ -∈ < h(x) - L < ∈... (2) Now, it is given that g(x) ≤ f(x) ≤ h(x). Subtracting L from each side, g(x) - L ≤ f(x) - L ≤ h(x) - L Choosing δ = minimum {δ1, δ2}, we have, whenever |x - a| < δ, -∈ < g(x) - L ≤ f(x) - L ≤ h(x) - L < ∈ (using (1) and (2)) -∈ < f(x) - L < ∈ ⇒ lim x → a f(x) = L. Hence the squeeze theorem is proved. Important Limits Using Squeeze (Sandwich) Theorem There are two limits that occur most frequently while solving the problems: lim x → 0 (sin x / x) and lim x → 0 (1 - cos x)/x. We can use the squeeze theorem to evaluate these two limits. After learning the process of evaluating these limits using the squeeze theorem, we can just memorize them so that we can use those values right away when solving other limits. We are going to prove: lim x → 0 (sin x / x) = 1 lim x → 0 (1 - cos x)/x = 0 To prove the first limit, we will prove an important relationship in trigonometry which says: cos x < (sin x)/x < 1. To prove this, consider a unit circle and let us say that 'x' is in the first quadrant (as sin(-x) = - sin x and cos (-x) = x, it is sufficient to prove the inequality in the first quadrant) such that ∠AOB = x (in radians). Draw a perpendicular from B to C. Draw a tangent AD at A (we know that tangent is perpendicular to radius). So both BC and AD are perpendicular to OA. From the above figure, Area of ΔOAB < Area of sector OAB < Area of ΔOAD Using the formulas of the area of triangle and area of the sector: (1/2) OA × BC < (1/2) (OA)2 × x < (1/2) OA × AD Multiplying each side by 2, OA × BC < (OA)2 × x < OA × AD Since, it is a unit circle, its radius, OA = 1. So the above inequality becomes: BC < x < AD ... (1) From ΔOBC, sin x = BC/OB ⇒ BC = sin x (as OB = radius of unit circle = 1) ... (2) From ΔOAD, tan x = AD/OA ⇒ AD = tan x (as OA = radius of unit circle = 1) ... (3) Substituting the values of BC and AD from (2) and (3) in (1): sin x < x < tan x Since x lies in the first quadrant, sin x is positive. Thus, dividing throughout by sin x doesn't affect the signs of inequality. (sin x)/(sin x) < x/(sin x) < (tan x)/(sin x) 1 < x/(sin x) < cos x (∵ (tan x)/(sin x) = (sin x/cos x)/(sin x/1) = cos x) Taking reciprocals: cos x < (sin x)/x < 1. Hence we proved the inequality. We will now use this to prove the first limit. Proving lim x → 0 (sin x / x) = 1 Using the above inequality, cos x < (sin x)/x < 1. Also, it is very clear that lim x → 0 cos x = cos 0 = 1 and lim x → 0 1 = 1. Hence, by squeeze theorem (sandwich theorem), lim x → 0 (sin x) / x = 1. Hence, we proved that lim x → 0 (sin x) / x = 1. Proving lim x → 0 (1 - cos x)/x = 0 Using the half-angle formulas, 1 - cos x = sin2 x/2. So the above limit becomes: lim x → 0 (2sin2 x/2) / x = lim x → 0 2 (sin x/2) (sin x/2) / x As x → 0, x/2 → 0. So the above limit becomes: = lim x → 0 (sin x/2) lim x/2 → 0 (sin x/2) / (x/2) By the above limit, we have lim x → 0 (sin x / x) = 1. Thus, the value of the right-side limit of the above step is 1. Thus, = (sin 0/2) (1) = 0 (1) = 0 Hence, we proved that lim x → 0 (1 - cos x)/x = 0. Important Notes on Squeeze Theorem: When we have to evaluate a limit using squeeze theorem (or sandwich theorem), remember the following trig inequalities. cos x < (sin x)/x < 1 -1 ≤ sin x ≤ 1, for any x in the domain of sin x -1 ≤ cos x ≤ 1, for any x in the domain of cos x ☛ Related Topics: Limits Calculator Derivative Calculator Integral Calculator Example 1: If 6 - x2 ≤ f(x) ≤ 6 + x2 then find the value of lim x → 0 f(x). Solution: We know that lim x → 0 6 - x2 = 6 - 02 = 6 and lim x → 0 6 + x2 = 6 + 02 = 6 Also, f(x) lies between 6 - x2 and 6 + x2. Thus, by squeeze theorem: lim x → 0 f(x) = 6. Answer: 6 Example 2: What is the value of the limit lim x → 0 x2 sin (1/x)? Solution: We know that -1 ≤ sin x ≤ 1 for any x. In the same way -1 ≤ sin (1/x) ≤ 1 (when x ≠ 0) Multiplying each side by x2 (This does not change the sign of inequality as x2 ≥ 0): -x2 ≤ sin (1/x) ≤ x2 Now, lim x → 0 -x2 = -02 = 0 and lim x → 0 x2 = lim x → 0 02 = 0. So by sandwich theorem, lim x → 0 x2 sin (1/x) = 0. Answer: 0 Example 3: Evaluate the limit lim x → 0 x ecos (1/x). Solution: We know that -1 ≤ cos x ≤ 1 for any x. In the same way -1 ≤ cos (1/x) ≤ 1 (when x ≠ 0) Raising each side by "e", e-1 ≤ ecos (1/x) ≤ e1 Multiply each side by x: xe-1 ≤ x ecos (1/x) ≤ xe Now, lim x → 0 xe-1 =0/e = 0 and lim x → 0 xe = 0(e) = 0 So by sandwich theorem, lim x → 0 x ecos (1/x) = 0. Answer: 0 View Answer > go to slidego to slidego to slide Have questions on basic mathematical concepts? Become a problem-solving champ using logic, not rules. Learn the why behind math with our certified experts Book a Free Trial Class FAQs on Squeeze Theorem The squeeze theorem states that if a function f(x) is such that g(x) ≤ f(x) ≤ h(x) and suppose that the limits of g(x) and h(x) as x tends to a is equal to L then lim x → a f(x) = L. It is known as "squeeze" theorem because it talks about a function f(x) that is "squeezed" between g(x) and h(x). What are the Other Names of Squeeze Theorem? The squeeze theorem is also known with other names such as: sandwich theorem carabinieri theorem squeeze lemma police theorem pinching theorem between theorem Can we Apply Sandwich Theorem for Infinite Limits? Yes, the sandwich theorem can be applied for infinite limits as well. For example, to find the limit lim x → ∞ (sin x) / x, we use the squeeze theorem as follows. We know that -1 ≤ sin x ≤ 1. Dividing by x, -1/x ≤ (sin x) / x ≤ 1/x. We know that lim x → ∞ (-1/x) = lim x → ∞ (1/x) = 0 and hence by squeeze theorem, lim x → ∞ (sin x) / x = 0. How Do We Apply Squeeze Theorem? To apply the squeeze theorem, first find between which two functions the given function lies. Then see whether the limits of those two functions at the given point are equal. If so, apply the squeeze theorem, by which the limit of the given function is also equal to the limit of each of the two functions. In this process, we can use one of the following popular inequalities: cos x < (sin x)/x < 1 -1 ≤ sin x ≤ 1 -1 ≤ cos x ≤ 1 What is the Name of the Mathematician Who Proposed Squeeze Theorem? The squeeze theorem was proposed by a mathematician called Hugo Steinhaus. It was later proved by another mathematician called Stefan Banach. Is Squeeze Theorem Only for Trig? In fact, the squeeze function is applicable for any type of function. But while solving the problems, we mostly come across the ones that are with trig functions when we apply the squeeze theorem.

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