

### Exercise 13.2

**Question 1:** Find the derivative of  $x^2 - 2$  at  $x = 10$ .

**Solution 1:** Let  $f(x) = x^2 - 2$ . Accordingly,

$$\begin{aligned} f'(10) &= \lim_{h \rightarrow 0} \frac{f(10+h) - f(10)}{h} \\ &= \lim_{h \rightarrow 0} \frac{[(10+h)^2 - 2] - (10^2 - 2)}{h} \\ &= \lim_{h \rightarrow 0} \frac{10^2 + 2 \cdot 10 \cdot h + h^2 - 2 - 10^2 + 2}{h} \\ &= \lim_{h \rightarrow 0} \frac{20h + h^2}{h} \\ &= \lim_{h \rightarrow 0} (20 + h) = 20 + 0 = 20 \end{aligned}$$

Thus, the derivative of  $x^2 - 2$  at  $x = 10$  is 20.

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**Question 2:** Find the derivative of  $99x$  at  $x = 100$ .

**Solution 2:** Let  $f(x) = 99x$ . Accordingly,

$$\begin{aligned} f'(100) &= \lim_{h \rightarrow 0} \frac{f(100+h) - f(100)}{h} \\ &= \lim_{h \rightarrow 0} \frac{99(100+h) - 99(100)}{h} \\ &= \lim_{h \rightarrow 0} \frac{99 \times 100 + 99h - 99 \times 100}{h} \\ &= \lim_{h \rightarrow 0} \frac{99h}{h} \\ &= \lim_{h \rightarrow 0} (99) = 99 \end{aligned}$$

Thus, the derivative of  $99x$  at  $x = 100$  is 99.

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**Question 3:** Find the derivative of  $x$  at  $x = 1$ .

**Solution 3:** Let  $f(x) = x$ . Accordingly,

$$\begin{aligned}f'(1) &= \lim_{h \rightarrow 0} \frac{f(1+h) - f(1)}{h} \\&= \lim_{h \rightarrow 0} \frac{(1+h) - 1}{h} \\&= \lim_{h \rightarrow 0} \frac{h}{h} \\&= \lim_{h \rightarrow 0} (1) = 1\end{aligned}$$

Thus, the derivative of  $x$  at  $x = 1$  is 1.

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**Question 4:** Find the derivative of the following functions from first principle.

(i)  $x^3 - 27$

(ii)  $(x - 1)(x - 2)$

(iii)  $\frac{1}{x^2}$

(iv)  $\frac{x+1}{x-1}$

**Solution 4:** (i) Let  $f(x) = x^3 - 27$ . Accordingly, from the first principle,

$$\begin{aligned}&= \lim_{h \rightarrow 0} \frac{[(x+h)^3 - 27] - (x^3 - 27)}{h} \\&= \lim_{h \rightarrow 0} \frac{x^3 + h^3 + 3x^2h + 3xh^2 - x^3}{h} \\&= \lim_{h \rightarrow 0} \frac{h^3 + 3x^2h + 3xh^2}{h} \\&= \lim_{h \rightarrow 0} (h^2 + 3x^2 + 3xh) \\&= 0 + 3x^2 + 0 = 3x^2\end{aligned}$$

(ii) Let  $f(x) = (x - 1)(x - 2)$ . Accordingly, from the first principle,

$$\begin{aligned}
&= \lim_{h \rightarrow 0} \frac{(x+h-1)(x+h-2) - (x-1)(x-2)}{h} \\
&= \lim_{h \rightarrow 0} \frac{(x^2 + hx - 2x + hx + h^2 - 2h - x - h + 2) - (x^2 - 2x - x + 2)}{h} \\
&= \lim_{h \rightarrow 0} \frac{(hx + hx + h^2 - 2h - h)}{h} \\
&= \lim_{h \rightarrow 0} \frac{2hx + h^2 - 3h}{h} \\
&= \lim_{h \rightarrow 0} (2x + h - 3) \\
&= 2x - 3
\end{aligned}$$

(iii) Let  $f(x) = \frac{1}{x^2}$ . Accordingly, from the first principle,

$$\begin{aligned}
&= \lim_{h \rightarrow 0} \frac{\frac{1}{(x+h)^2} - \frac{1}{x^2}}{h} \\
&= \lim_{h \rightarrow 0} \frac{1}{h} \left[ \frac{x^2 - (x+h)^2}{x^2(x+h)^2} \right] \\
&= \lim_{h \rightarrow 0} \frac{1}{h} \left[ \frac{x^2 - x^2 - 2hx - h^2}{x^2(x+h)^2} \right] \\
&= \lim_{h \rightarrow 0} \frac{1}{h} \left[ \frac{-h^2 - 2hx}{x^2(x+h)^2} \right] \\
&= \lim_{h \rightarrow 0} \left[ \frac{-h^2 - 2x}{x^2(x+h)^2} \right] \\
&= \frac{0 - 2x}{x^2(x+0)^2} = \frac{-2}{x^3}
\end{aligned}$$

(iv) Let  $f(x) = \frac{x+1}{x-1}$ . Accordingly, from the first principle,

$$\begin{aligned}
 &= \lim_{h \rightarrow 0} \frac{\left( \frac{x+h+1}{x+h-1} - \frac{x+1}{x-1} \right)}{h} \\
 &= \lim_{h \rightarrow 0} \frac{1}{h} \left[ \frac{(x-1)(x+h+1) - (x+1)(x+h-1)}{(x-1)(x+h-1)} \right] \\
 &= \lim_{h \rightarrow 0} \frac{1}{h} \left[ \frac{(x^2 + hx + x - x - h - 1) - (x^2 + hx - x + x + h - 1)}{(x-1)(x+h-1)} \right] \\
 &= \lim_{h \rightarrow 0} \frac{1}{h} \left[ \frac{-2h}{(x-1)(x+h-1)} \right] \\
 &= \lim_{h \rightarrow 0} \left[ \frac{-2}{(x-1)(x+h-1)} \right] \\
 &= \frac{-2}{(x-1)(x-1)} = \frac{-2}{(x-1)^2}
 \end{aligned}$$


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**Question 5:** For the function

$$F(x) = \frac{x^{100}}{100} + \frac{x^{99}}{99} + \dots + \frac{x^2}{2} + x + 1$$

Prove that  $f'(1) = 100 f'(0)$

**Solution 5:** The given function is

$$F(x) = \frac{x^{100}}{100} + \frac{x^{99}}{99} + \dots + \frac{x^2}{2} + x + 1$$

$$\frac{d}{dx} f(x) = \frac{d}{dx} \left[ \frac{x^{100}}{100} + \frac{x^{99}}{99} + \dots + \frac{x^2}{2} + x + 1 \right]$$

$$\frac{d}{dx} f(x) = \frac{d}{dx} \left( \frac{x^{100}}{100} \right) + \frac{d}{dx} \left( \frac{x^{99}}{99} \right) + \dots + \frac{d}{dx} \left( \frac{x^2}{2} \right) + \frac{d}{dx} (x) + \frac{d}{dx} (1)$$

On using theorem  $\frac{d}{dx}(x^n) = nx^{n-1}$ , we obtain

$$\frac{d}{dx}f(x) = \frac{100x^{99}}{100} + \frac{99x^{98}}{99} + \dots + \frac{2x}{2} + 1 + 0$$

$$= x^{99} + x^{98} + \dots + x + 1$$

$$\therefore f'(x) = x^{99} + x^{98} + \dots + x + 1$$

At  $x = 0$ ,

$$f(0) = 1$$

At  $x = 1$ ,

$$f'(1) = 1^{99} + 1^{98} + \dots + 1 + 1 = [1 + 1 + \dots + 1 + 1]_{100 \text{ terms}} = 1 \times 100 = 100$$

Thus,  $f(1) = 100 f(0)$

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**Question 6:** Find the derivative of  $x^n + ax^{n-1} + a^2x^{n-2} + \dots + a^{n-1}x + a^n$  for some fixed real number  $a$ .

**Solution 6:** Let  $f(x) = x^n + ax^{n-1} + a^2x^{n-2} + \dots + a^{n-1}x + a^n$

$$\begin{aligned} \frac{d}{dx}f(x) &= \frac{d}{dx}(x^n + ax^{n-1} + a^2x^{n-2} + \dots + a^{n-1}x + a^n) \\ &= \frac{d}{dx}(x^n) + a \frac{d}{dx}(x^{n-1}) + a^2 \frac{d}{dx}(x^{n-2}) + \dots + a^{n-1} \frac{d}{dx}(x) + a^n \frac{d}{dx}(1) \end{aligned}$$

On using theorem  $\frac{d}{dx}(x^n) = nx^{n-1}$ , we obtain

$$f'(x) = nx^{n-1} + a(n-1)x^{n-2} + a^2(n-2)x^{n-3} + \dots + a^{n-1} + a^n(0)$$

$$\therefore f'(x) = nx^{n-1} + a(n-1)x^{n-2} + a^2(n-2)x^{n-3} + \dots + a^{n-1}$$


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**Question 7:** For some constants  $a$  and  $b$ , find the derivative of

(i)  $(x - a)(x - b)$

(ii)  $(ax^2 + b)^2$

(iii)  $\frac{x-a}{x-b}$

**Solution 7:** (i) Let  $f(x) = (x - a)(x - b)$

$$\Rightarrow f(x) = x^2 - (a+b)x + ab$$

$$\therefore f'(x) = \frac{d}{dx}(x^2 - (a+b)x + ab)$$

$$= \frac{d}{dx}(x^2) - (a+b) \frac{d}{dx}(x) + \frac{d}{dx}(ab)$$

On using theorem  $\frac{d}{dx}(x^n) = nx^{n-1}$ , we obtain

$$f'(x) = 2x - (a+b) + 0$$

$$= 2x - a - b$$

(ii) Let  $f(x) = (ax^2 + b)^2$

$$\Rightarrow f(x) = a^2x^4 + 2abx^2 + b^2$$

$$\therefore f'(x) = \frac{d}{dx}(a^2x^4 + 2abx^2 + b^2)$$

$$= a^2 \frac{d}{dx}(x^4) + 2ab \frac{d}{dx}(x^2) + \frac{d}{dx}b^2$$

On using theorem  $\frac{d}{dx}(x^n) = nx^{n-1}$ , we obtain

$$f'(x) = a^2(4x^3) + 2ab(2x) + b^2(0)$$

$$= 4a^2x^3 + 4abx$$

$$= 4ax(ax^2 + b)$$

(iii) Let  $f(x) = \frac{x-a}{x-b}$

$$\Rightarrow f'(x) = \frac{d}{dx}\left(\frac{x-a}{x-b}\right)$$

By quotient rule,

$$f'(x) = \frac{(x-b) \frac{d}{dx}(x-a) - (x-a) \frac{d}{dx}(x-b)}{(x-b)^2}$$

$$= \frac{(x-b)(1) - (x-a)(1)}{(x-b)^2}$$

$$= \frac{x-b-x+a}{(x-b)^2}$$

$$= \frac{a-b}{(x-b)^2}$$

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**Question 8:** Find the derivative of  $\frac{x^n - a^n}{x-a}$  for some constant a.

**Solution 8:** Let  $f(x) = \frac{x^n - a^n}{x-a}$

$$\Rightarrow f'(x) = \frac{d}{dx} \left( \frac{x^n - a^n}{x-a} \right)$$

By quotient rule,

$$f'(x) = \frac{(x-a) \frac{d}{dx} (x^n - a^n) - (x^n - a^n) \frac{d}{dx} (x-a)}{(x-a)^2}$$

$$= \frac{(x-a)(nx^{n-1} - 0) - (x^n - a^n)}{(x-a)^2}$$

$$= \frac{nx^n - anx^{n-1} - x^n + a^n}{(x-a)^2}$$

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**Question 9:** Find the derivative of

(i)  $2x - \frac{3}{4}$

(ii)  $(5x^3 + 3x - 1)(x - 1)$

(iii)  $x^{-3}(5 + 3x)$

(iv)  $x^5(3 - 6x^{-9})$

(v)  $x^{-4}(3 - 4x^{-5})$

(vi)  $\frac{2}{x+1} - \frac{x^2}{3x-1}$

**Solution 9:** (i) Let  $f(x) = 2x - \frac{3}{4}$

$$\begin{aligned}f'(x) &= \frac{d}{dx} \left( 2x - \frac{3}{4} \right) \\&= 2 \frac{d}{dx} (x) - \frac{d}{dx} \left( \frac{3}{4} \right) \\&= 2 - 0 \\&= 2\end{aligned}$$

(ii) Let  $f(x) = (5x^3 + 3x - 1)(x - 1)$

By Leibnitz product rule,

$$\begin{aligned}f'(x) &= (5x^3 + 3x - 1) \frac{d}{dx} (x - 1) + (x - 1) \frac{d}{dx} (5x^3 + 3x - 1) \\&= (5x^3 + 3x - 1)(1) + (x - 1)(15x^2 + 3 - 0) \\&= (5x^3 + 3x - 1) + (x - 1)(15x^2 + 3) \\&= 5x^3 + 3x - 1 + 15x^3 + 3x - 15x^2 - 3 \\&= 20x^3 - 15x^2 + 6x - 4\end{aligned}$$

(iii) Let  $f(x) = x^{-3}(5 + 3x)$

By Leibnitz product rule,

$$\begin{aligned}f'(x) &= x^{-3} \frac{d}{dx} (5 + 3x) + (5 + 3x) \frac{d}{dx} (x^{-3}) \\&= x^{-3}(0 + 3) + (5 + 3x)(3x^{-3-1}) \\&= x^{-3}(3) + (5 + 3x)(3x^{-4}) \\&= 3x^{-3} - 15x^{-4} - 9x^{-3} \\&= -6x^{-3} - 15x^{-4} \\&= -3x^{-3} \left( 2 + \frac{5}{x} \right) \\&= \frac{-3x^{-3}}{x} (2x + 5)\end{aligned}$$



$$= \frac{-3}{x^4} (5 + 2x)$$

(iv) Let  $f(x) = x^5(3 - 6x^{-9})$

By Leibnitz product rule,

$$\begin{aligned} f'(x) &= x^5 \frac{d}{dx}(3 - 6x^{-9}) + (3 - 6x^{-9}) \frac{d}{dx}(x^5) \\ &= x^5 \{0 - 6(-9)x^{-9-1}\} + (3 - 6x^{-9})(5x^4) \\ &= x^5(54x^{-10}) + 15x^4 - 30x^{-5} \\ &= 54x^{-5} + 15x^4 - 30x^{-5} \\ &= 24x^{-5} + 15x^4 \\ &= 15x^4 + \frac{24}{x^5} \end{aligned}$$

(v) Let  $f(x) = x^{-4}(3 - 4x^{-5})$

By Leibnitz product rule,

$$\begin{aligned} f'(x) &= x^{-4} \frac{d}{dx}(3 - 4x^{-5}) + (3 - 4x^{-5}) \frac{d}{dx}(x^{-4}) \\ &= x^{-4} \{0 - 4(-5)x^{-5-1}\} + (3 - 4x^{-5})(-4)x^{-4-1} \\ &= x^{-4}(20x^{-6}) + (3 - 4x^{-5})(-4x^{-5}) \\ &= 20x^{-10} - 12x^{-5} + 16x^{-10} \\ &= 36x^{-10} - 12x^{-5} \\ &= \frac{12}{x^{-5}} + \frac{36}{x^{10}} \end{aligned}$$

(vi) Let  $f(x) = \frac{2}{x+1} - \frac{x^2}{3x-1}$

$$f'(x) = \frac{d}{dx} \left( \frac{2}{x+1} \right) - \frac{d}{dx} \left( \frac{x^2}{3x-1} \right)$$

By quotient rule,

$$\begin{aligned}
f'(x) &= \left[ \frac{(x+1) \frac{d}{dx}(2) - 2 \frac{d}{dx}(x+1)}{(x+1)^2} \right] - \left[ \frac{(3x-1) \frac{d}{dx}(x^2) - x^2 \frac{d}{dx}(3x-1)}{(3x-1)^2} \right] \\
&= \left[ \frac{(x+1)(0) - 2(1)}{(x+1)^2} \right] - \left[ \frac{(3x-1)(2x) - x^2(3)}{(3x-1)^2} \right] \\
&= \frac{-2}{(x+1)^2} - \left[ \frac{6x^2 - 2x - 3x^2}{(3x-1)^2} \right] \\
&= \frac{-2}{(x+1)^2} - \left[ \frac{3x^2 - 2x^2}{(3x-1)^2} \right] \\
&= \frac{-2}{(x+1)^2} - \frac{x(3x-2)}{(3x-1)^2}
\end{aligned}$$


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**Question 10:** Find the derivative of  $\cos x$  from first principle.

**Solution 10:** Let  $f(x) = \cos x$ . Accordingly, from the first principle,

$$\begin{aligned}
&= \lim_{h \rightarrow 0} \left[ \frac{\cos(x+h) - \cos(x)}{h} \right] \\
&= \lim_{h \rightarrow 0} \left[ \frac{\cos x \cos h - \sin x \sin h - \cos x}{h} \right] \\
&= \lim_{h \rightarrow 0} \left[ \frac{-\cos x(1 - \cos h) - \sin x \sin h}{h} \right] \\
&= -\cos x \left[ \lim_{h \rightarrow 0} \left( \frac{1 - \cos h}{h} \right) \right] - \sin x \left[ \lim_{h \rightarrow 0} \left( \frac{\sin h}{h} \right) \right] \\
&= -\cos x(0) - \sin x(1) \quad \left[ \lim_{h \rightarrow 0} \frac{1 - \cos h}{h} = 0 \text{ and } \lim_{h \rightarrow 0} \frac{\sin h}{h} = 1 \right]
\end{aligned}$$

$$\therefore f'(x) = -\sin x$$


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**Question 11:** Find the derivative of the following functions:

(i)  $\sin x \cos x$

(ii)  $\sec x$

(iii)  $5\sec x + 4\cos x$

(iv)  $\operatorname{cosec} x$

(v)  $3\cot x + 5\operatorname{cosec} x$

(vi)  $5\sin x - 6\cos x + 7$

(vii)  $2\tan x - 7\sec x$

**Solution 11:** (i) Let  $f(x) = \sin x \cos x$ . Accordingly, from the first principle,

$$= \lim_{h \rightarrow 0} \frac{\sin(x+h)\cos(x+h) - \sin x \cos x}{h}$$

$$= \lim_{h \rightarrow 0} \frac{1}{2h} [2\sin(x+h)\cos(x+h) - 2\sin x \cos x]$$

$$= \lim_{h \rightarrow 0} \frac{1}{2h} [\sin 2(x+h) - \sin 2x]$$

$$= \lim_{h \rightarrow 0} \frac{1}{2h} \left[ 2\cos \frac{2x+2h+2x}{2} \cdot \sin \frac{2x+2h-2x}{2} \right]$$

$$= \lim_{h \rightarrow 0} \frac{1}{2h} \left[ 2\cos \frac{4x+2h}{2} \cdot \sin \frac{2h}{2} \right]$$

$$= \lim_{h \rightarrow 0} \frac{1}{2h} [\cos(2x+h) \sin h]$$

$$= \lim_{h \rightarrow 0} \cos(2x+h) \cdot \lim_{h \rightarrow 0} \frac{\sin h}{h}$$

$$= \cos(2x+h) \cdot 1$$

$$= \cos 2x$$

(ii) Let  $f(x) = \sec x$ . Accordingly, from the first principle,

$$\begin{aligned}
&= \lim_{h \rightarrow 0} \frac{\sec(x+h) - \sec x}{h} \\
&= \lim_{h \rightarrow 0} \frac{1}{h} \left[ \frac{1}{\cos(x+h)} - \frac{1}{\cos x} \right] \\
&= \lim_{h \rightarrow 0} \frac{1}{h} \left[ \frac{\cos x - \cos(x+h)}{\cos x \cos(x+h)} \right] \\
&= \frac{1}{\cos x} \cdot \lim_{h \rightarrow 0} \frac{1}{h} \left[ \frac{-2 \sin\left(\frac{x+x+h}{2}\right) \sin\left(\frac{x-x-h}{2}\right)}{\cos(x+h)} \right] \\
&= \frac{1}{\cos x} \cdot \lim_{h \rightarrow 0} \frac{1}{h} \left[ \frac{-2 \sin\left(\frac{2x+h}{2}\right) \sin\left(\frac{-h}{2}\right)}{\cos(x+h)} \right] \\
&= \frac{1}{\cos x} \cdot \lim_{h \rightarrow 0} \frac{1}{2h} \left[ \frac{-2 \sin\left(\frac{2x+h}{2}\right) \frac{\sin\left(\frac{-h}{2}\right)}{\left(\frac{h}{2}\right)}}{\cos(x+h)} \right] \\
&= \frac{1}{\cos x} \cdot \lim_{h \rightarrow 0} \frac{\sin\left(\frac{h}{2}\right)}{\left(\frac{h}{2}\right)} \cdot \lim_{h \rightarrow 0} \frac{\sin\left(\frac{2x+h}{2}\right)}{\cos(x+h)} \\
&= \frac{1}{\cos x} \cdot 1 \cdot \frac{\sin x}{\cos x} \\
&= \sec x \tan x
\end{aligned}$$

(iii) Let  $f(x) = 5\sec x + 4\cos x$ . Accordingly, from the first principle,

$$= \lim_{h \rightarrow 0} \frac{5\sec(x+h) + 4\cos(x+h) - [5\sec x + 4\cos x]}{h}$$

$$\begin{aligned}
&= 5 \lim_{h \rightarrow 0} \frac{[\sec(x+h) - \sec x]}{h} + 4 \lim_{h \rightarrow 0} \frac{[\cos(x+h) - \cos x]}{h} \\
&= 5 \lim_{h \rightarrow 0} \frac{1}{h} \left[ \frac{1}{\cos(x+h)} - \frac{1}{\cos x} \right] + 4 \lim_{h \rightarrow 0} \frac{1}{h} [\cos(x+h) - \cos x] \\
&= 5 \lim_{h \rightarrow 0} \frac{1}{h} \left[ \frac{\cos x - \cos(x+h)}{\cos x \cos(x+h)} \right] + 4 \lim_{h \rightarrow 0} \frac{1}{h} [\cos x \cos h - \sin x \sin h - \cos x] \\
&= \frac{5}{\cos x} \cdot \lim_{h \rightarrow 0} \frac{1}{h} \left[ \frac{-2 \sin\left(\frac{2x+h}{2}\right) \sin\left(\frac{-h}{2}\right)}{\cos(x+h)} \right] + 4 \left[ -\cos x \lim_{h \rightarrow 0} \frac{(1 - \cos x)}{h} - \sin x \lim_{h \rightarrow 0} \frac{\sin h}{h} \right] \\
&= \frac{5}{\cos x} \cdot \lim_{h \rightarrow 0} \left[ \frac{\sin\left(\frac{2x+h}{2}\right) \sin\left(\frac{-h}{2}\right)}{\cos(x+h) \left(\frac{h}{2}\right)} \right] + 4[-\cos x(0) - \sin x(1)] \\
&= \frac{5}{\cos x} \cdot \lim_{h \rightarrow 0} \left[ \frac{\sin\left(\frac{h}{2}\right)}{\left(\frac{h}{2}\right)} \cdot \lim_{h \rightarrow 0} \frac{\sin\left(\frac{2x+h}{2}\right)}{\cos(x+h)} \right] - 4 \sin x \\
&= \frac{5}{\cos x} \cdot \frac{\sin x}{\cos x} \cdot 1 - 4 \sin x \\
&= 5 \sec x \tan x - 4 \sin x
\end{aligned}$$

(iv) Let  $f(x) = \operatorname{cosec} x$ . Accordingly, from the first principle,

$$\begin{aligned}
&= \lim_{h \rightarrow 0} \frac{1}{h} [\operatorname{cosec}(x+h) - \operatorname{cosec} x] \\
&= \lim_{h \rightarrow 0} \frac{1}{h} \left[ \frac{1}{\sin(x+h)} - \frac{1}{\sin x} \right] \\
&= \lim_{h \rightarrow 0} \frac{1}{h} \left[ \frac{\sin x - \sin(x+h)}{\sin x \sin(x+h)} \right]
\end{aligned}$$

$$= \lim_{h \rightarrow 0} \frac{1}{h} \left[ \frac{2 \cos\left(\frac{x+x+h}{2}\right) \cdot \sin\left(\frac{x-x-h}{2}\right)}{\sin x \sin(x+h)} \right]$$

$$= \lim_{h \rightarrow 0} \frac{1}{h} \left[ \frac{2 \cos\left(\frac{2x+h}{2}\right) \cdot \sin\left(\frac{-h}{2}\right)}{\sin x \sin(x+h)} \right]$$

$$= \lim_{h \rightarrow 0} \left[ \frac{-\cos\left(\frac{2x+h}{2}\right) \frac{\sin\left(\frac{-h}{2}\right)}{\left(\frac{h}{2}\right)}}{\sin x \sin(x+h)} \right]$$

$$= \lim_{h \rightarrow 0} \left( \frac{-\cos\left(\frac{2x+h}{2}\right)}{\sin x \sin(x+h)} \right) \cdot \lim_{\frac{h}{2} \rightarrow 0} \frac{\sin\left(\frac{h}{2}\right)}{\left(\frac{h}{2}\right)}$$

$$= \left( \frac{-\cos x}{\sin x \sin x} \right) \cdot 1$$

$$= -\operatorname{cosec} x \cot x$$

(v) Let  $f(x) = 3\cot x + 5\operatorname{cosec} x$ . Accordingly, from the first principle,

$$= \lim_{h \rightarrow 0} \frac{1}{h} [3\cot(x+h) + 5\operatorname{cosec}(x+h) - 3\cot x - 5\operatorname{cosec} x]$$

$$= 3 \lim_{h \rightarrow 0} \frac{1}{h} [\cot(x+h) - \cot x] + 5 \lim_{h \rightarrow 0} \frac{1}{h} [\operatorname{cosec}(x+h) - \operatorname{cosec} x] \quad \dots(1)$$

$$\text{Now, } \lim_{h \rightarrow 0} \frac{1}{h} [\cot(x+h) - \cot x] = \lim_{h \rightarrow 0} \frac{1}{h} \left[ \frac{\cos(x+h)}{\sin(x+h)} - \frac{\cos x}{\sin x} \right]$$

$$= \lim_{h \rightarrow 0} \frac{1}{h} \left[ \frac{\cos(x+h) \sin x - \cos x \sin(x+h)}{\sin x \sin(x+h)} \right]$$

$$= \lim_{h \rightarrow 0} \frac{1}{h} \left[ \frac{\sin(x-x-h)}{\sin x \sin(x+h)} \right]$$

$$\begin{aligned}
&= \lim_{h \rightarrow 0} \frac{1}{h} \left[ \frac{\sin(-h)}{\sin x \sin(x+h)} \right] \\
&= \lim_{h \rightarrow 0} \frac{\sin h}{h} \cdot \lim_{h \rightarrow 0} \left[ \frac{1}{\sin x \sin(x+h)} \right] \\
&= -1 \cdot \frac{1}{\sin x \sin(x+h)} = \frac{-1}{\sin^2 x} = -\operatorname{cosec}^2 x \quad \dots(2)
\end{aligned}$$

$$\lim_{h \rightarrow 0} \frac{1}{h} [\operatorname{cosec}(x+h) - \operatorname{cosec} x] = \lim_{h \rightarrow 0} \frac{1}{h} \left[ \frac{1}{\sin(x+h)} - \frac{1}{\sin x} \right]$$

$$= \lim_{h \rightarrow 0} \frac{1}{h} \left[ \frac{\sin x - \sin(x+h)}{\sin x \sin(x+h)} \right]$$

$$= \lim_{h \rightarrow 0} \frac{1}{h} \left[ \frac{2 \cos\left(\frac{x+x+h}{2}\right) \cdot \sin\left(\frac{x-x-h}{2}\right)}{\sin x \sin(x+h)} \right]$$

$$= \lim_{h \rightarrow 0} \frac{1}{h} \left[ \frac{2 \cos\left(\frac{2x+h}{2}\right) \cdot \sin\left(\frac{-h}{2}\right)}{\sin x \sin(x+h)} \right]$$

$$= \lim_{h \rightarrow 0} \frac{-\cos\left(\frac{2x+h}{2}\right) \cdot \frac{\sin\left(\frac{-h}{2}\right)}{\left(\frac{h}{2}\right)}}{\sin x \sin(x+h)}$$

$$= \lim_{h \rightarrow 0} \left( \frac{-\cos\left(\frac{2x+h}{2}\right)}{\sin x \sin(x+h)} \right) \cdot \lim_{h \rightarrow 0} \frac{\sin\left(\frac{h}{2}\right)}{\left(\frac{h}{2}\right)}$$

$$= \left( \frac{-\cos x}{\sin x \sin x} \right) \cdot 1$$

$$= -\operatorname{cosec} x \cot x \quad \dots(3)$$

From (1), (2), and (3), we obtain

$$f'(x) = -3\operatorname{cosec}^2 x - 5\operatorname{cosec} x \cot x$$

(vi) Let  $f(x) = 5\sin x - 6\cos x + 7$ . Accordingly, from the first principle,

$$\begin{aligned}
 &= \lim_{h \rightarrow 0} \frac{1}{h} [5\sin(x+h) - 6\cos(x+h) + 7 - 5\sin x + 6\cos x - 7] \\
 &= 5 \lim_{h \rightarrow 0} \frac{1}{h} [\sin(x+h) - \sin x] - 6 \lim_{h \rightarrow 0} \frac{1}{h} [\cos(x+h) - \cos x] \\
 &= 5 \lim_{h \rightarrow 0} \frac{1}{h} \left[ 2 \cos \left( \frac{x+h+x}{2} \right) \cdot \sin \left( \frac{x+h-x}{2} \right) \right] - 6 \lim_{h \rightarrow 0} \frac{\cos x \cos h - \sin x \sin h - \cos x}{h} \\
 &= 5 \lim_{h \rightarrow 0} \frac{1}{h} \left[ 2 \cos \left( \frac{2x+h}{2} \right) \cdot \sin \left( \frac{h}{2} \right) \right] - 6 \lim_{h \rightarrow 0} \left[ \frac{-\cos x(1 - \cos h) - \sin x \sin h}{h} \right] \\
 &= 5 \lim_{h \rightarrow 0} \frac{1}{h} \left[ \cos \left( \frac{2x+h}{2} \right) \cdot \frac{\sin \left( \frac{h}{2} \right)}{\left( \frac{h}{2} \right)} \right] - 6 \lim_{h \rightarrow 0} \left[ \frac{-\cos x(1 - \cos h)}{h} - \frac{\sin x \sin h}{h} \right] \\
 &= 5 \left[ \lim_{h \rightarrow 0} \cos \left( \frac{2x+h}{2} \right) \right] \left[ \lim_{h \rightarrow 0} \frac{\sin \left( \frac{h}{2} \right)}{\left( \frac{h}{2} \right)} \right] - 6 \left[ -\cos x \left( \lim_{h \rightarrow 0} \frac{1 - \cos h}{h} \right) - \sin x \left( \lim_{h \rightarrow 0} \frac{\sin h}{h} \right) \right] \\
 &= 5 \cos x \cdot 1 - 6 [(-\cos x) \cdot (0) - \sin x \cdot 1] \\
 &= 5 \cos x + 6 \sin x
 \end{aligned}$$

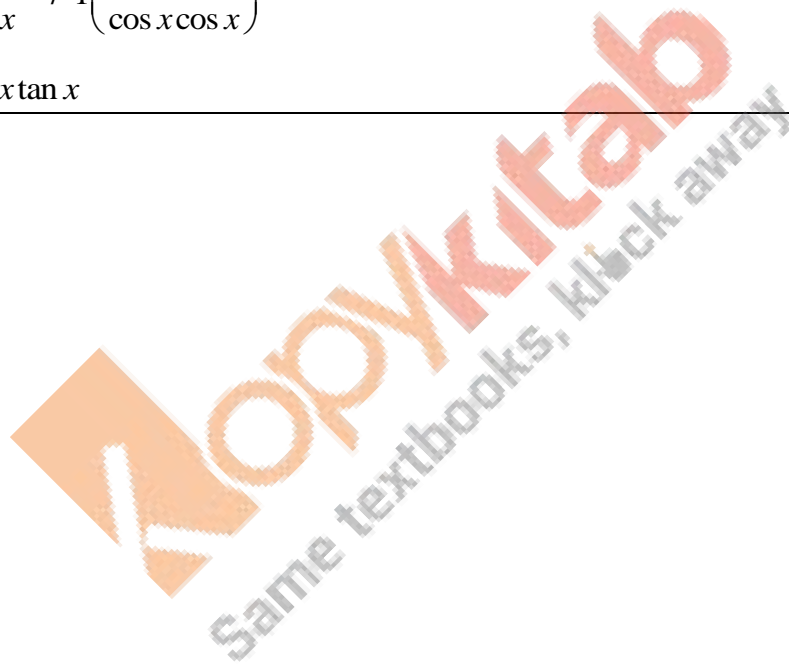
(vii) Let  $f(x) = 2 \tan x - 7 \sec x$ . Accordingly, from the first principle,

$$\begin{aligned}
 &= \lim_{h \rightarrow 0} \frac{1}{h} [2\tan(x+h) - 7\sec(x+h) - 2\tan x + 7\sec x] \\
 &= 2 \lim_{h \rightarrow 0} \frac{1}{h} [\tan(x+h) - \tan x] - 7 \lim_{h \rightarrow 0} \frac{1}{h} [\sec(x+h) - \sec x] \\
 &= 2 \lim_{h \rightarrow 0} \frac{1}{h} \left[ \frac{\sin(x+h)}{\cos(x+h)} - \frac{\sin x}{\cos x} \right] - 7 \lim_{h \rightarrow 0} \frac{1}{h} \left[ \frac{1}{\operatorname{cosec}(x+h)} - \frac{1}{\operatorname{cosec} x} \right] \\
 &= 2 \lim_{h \rightarrow 0} \frac{1}{h} \left[ \frac{\cos x \sin(x+h) - \sin x \cos(x+h)}{\cos x \cos(x+h)} \right] - 7 \lim_{h \rightarrow 0} \frac{1}{h} \left[ \frac{\cos x - \cos(x+h)}{\cos x \cos(x+h)} \right]
 \end{aligned}$$



$$\begin{aligned}
&= 2 \lim_{h \rightarrow 0} \frac{1}{h} \left[ \frac{\sin x + h - x}{\cos x \cos(x+h)} \right] - 7 \lim_{h \rightarrow 0} \frac{1}{h} \left[ \frac{-2 \sin\left(\frac{x+x+h}{2}\right) \sin\left(\frac{x-x-h}{2}\right)}{\cos x \cos(x+h)} \right] \\
&= 2 \left[ \lim_{h \rightarrow 0} \left( \frac{\sin h}{h} \right) \frac{1}{\cos x \cos(x+h)} \right] - 7 \lim_{h \rightarrow 0} \frac{1}{h} \left[ \frac{-2 \sin\left(\frac{2x+h}{2}\right) \sin\left(\frac{-h}{2}\right)}{\cos x \cos(x+h)} \right] \\
&= 2 \left( \lim_{h \rightarrow 0} \frac{\sin h}{h} \right) \left[ \lim_{h \rightarrow 0} \frac{1}{\cos x \cos(x+h)} \right] - 7 \left( \lim_{h \rightarrow 0} \frac{\sin\left(\frac{h}{2}\right)}{\frac{h}{2}} \right) \left( \lim_{h \rightarrow 0} \frac{\sin\left(\frac{2x+h}{2}\right)}{\cos x \cos(x+h)} \right) \\
&= 2 \cdot 1 \cdot \frac{1}{\cos x \cos x} - 7 \cdot 1 \cdot \left( \frac{\sin x}{\cos x \cos x} \right) \\
&= 2 \sec^2 x - 7 \sec x \tan x
\end{aligned}$$


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