

Difference and Difference Quotient. Part III

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Summary. In this article, we give some important theorems of forward difference, backward difference, central difference and difference quotient and forward difference, backward difference, central difference and difference quotient formulas of some special functions.

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The terminology and notation used in this paper have been introduced in the following papers: [6], [2], [1], [4], [11], [7], [5], [8], [12], [9], [10], and [3].

We follow the rules: n, m are elements of \mathbb{N} , $h, k, r, r_1, r_2, x, x_0, x_1, x_2, x_3$ are real numbers, and f, f_1, f_2 are functions from \mathbb{R} into \mathbb{R} .

Next we state a number of propositions:

- (1) $(\delta_h[f])(x) = (\Delta_{\frac{h}{2}}[f])(x) - (\Delta_{-\frac{h}{2}}[f])(x)$.
- (2) $(\Delta_{-\frac{h}{2}}[f])(x) = -(\nabla_{\frac{h}{2}}[f])(x)$.
- (3) $(\delta_h[f])(x) = (\nabla_{\frac{h}{2}}[f])(x) - (\nabla_{-\frac{h}{2}}[f])(x)$.
- (4) $(\vec{\Delta}_h[r f_1 + f_2])(n+1)(x) = r \cdot (\vec{\Delta}_h[f_1])(n+1)(x) + (\vec{\Delta}_h[f_2])(n+1)(x)$.
- (5) $(\vec{\Delta}_h[f_1 + r f_2])(n+1)(x) = (\vec{\Delta}_h[f_1])(n+1)(x) + r \cdot (\vec{\Delta}_h[f_2])(n+1)(x)$.
- (6) $(\vec{\Delta}_h[r_1 f_1 - r_2 f_2])(n+1)(x) = r_1 \cdot (\vec{\Delta}_h[f_1])(n+1)(x) - r_2 \cdot (\vec{\Delta}_h[f_2])(n+1)(x)$.
- (7) $(\vec{\Delta}_h[f])(1) = \Delta_h[f]$.
- (8) $(\vec{\nabla}_h[r f_1 + f_2])(n+1)(x) = r \cdot (\vec{\nabla}_h[f_1])(n+1)(x) + (\vec{\nabla}_h[f_2])(n+1)(x)$.
- (9) $(\vec{\nabla}_h[f_1 + r f_2])(n+1)(x) = (\vec{\nabla}_h[f_1])(n+1)(x) + r \cdot (\vec{\nabla}_h[f_2])(n+1)(x)$.
- (10) $(\vec{\nabla}_h[r_1 f_1 - r_2 f_2])(n+1)(x) = r_1 \cdot (\vec{\nabla}_h[f_1])(n+1)(x) - r_2 \cdot (\vec{\nabla}_h[f_2])(n+1)(x)$.

- (11) $(\vec{\nabla}_h[f])(1) = \nabla_h[f]$.
- (12) $(\vec{\nabla}_h[(\vec{\nabla}_h[f])(m)])(n)(x) = (\vec{\nabla}_h[f])(m+n)(x)$.
- (13) $(\vec{\delta}_h[r f_1 + f_2])(n+1)(x) = r \cdot (\vec{\delta}_h[f_1])(n+1)(x) + (\vec{\delta}_h[f_2])(n+1)(x)$.
- (14) $(\vec{\delta}_h[f_1 + r f_2])(n+1)(x) = (\vec{\delta}_h[f_1])(n+1)(x) + r \cdot (\vec{\delta}_h[f_2])(n+1)(x)$.
- (15) $(\vec{\delta}_h[r_1 f_1 - r_2 f_2])(n+1)(x) = r_1 \cdot (\vec{\delta}_h[f_1])(n+1)(x) - r_2 \cdot (\vec{\delta}_h[f_2])(n+1)(x)$.
- (16) $(\vec{\delta}_h[f])(1) = \delta_h[f]$.
- (17) $(\vec{\delta}_h[(\vec{\delta}_h[f])(m)])(n)(x) = (\vec{\delta}_h[f])(m+n)(x)$.
- (18) If $(\vec{\Delta}_h[f])(n)(x) = (\vec{\delta}_h[f])(n)(x + \frac{n}{2} \cdot h)$, then $(\vec{\nabla}_h[f])(n)(x) = (\vec{\delta}_h[f])(n)(x - \frac{n}{2} \cdot h)$.
- (19) If $(\vec{\Delta}_h[f])(n)(x) = (\vec{\delta}_h[f])(n)(x + \frac{n-1}{2} \cdot h + \frac{h}{2})$, then $(\vec{\nabla}_h[f])(n)(x) = (\vec{\delta}_h[f])(n)(x - \frac{n-1}{2} \cdot h - \frac{h}{2})$.
- (20) $\Delta[f](x, x+h) = \frac{(\Delta_h[f])(x)}{h}$.
- (21) $\Delta[f](x-h, x) = \frac{(\nabla_h[f])(x)}{h}$.
- (22) $\Delta[f](x - \frac{h}{2}, x + \frac{h}{2}) = \frac{(\delta_h[f])(x)}{h}$.
- (23) $\Delta[f](x - \frac{h}{2}, x + \frac{h}{2}) = \frac{(\vec{\delta}_h[f])(1)(x)}{h}$.
- (24) If $h \neq 0$, then $\Delta[f](x-h, x, x+h) = \frac{(\vec{\delta}_h[f])(2)(x)}{2 \cdot h \cdot h}$.
- (25) $\Delta[f_1 - f_2](x_0, x_1) = \Delta[f_1](x_0, x_1) - \Delta[f_2](x_0, x_1)$.
- (26) $\Delta[r f_1 + f_2](x_0, x_1) = r \cdot \Delta[f_1](x_0, x_1) + \Delta[f_2](x_0, x_1)$.
- (27) $\Delta[r f_1 - f_2](x_0, x_1) = r \cdot \Delta[f_1](x_0, x_1) - \Delta[f_2](x_0, x_1)$.
- (28) $\Delta[f_1 + r f_2](x_0, x_1) = \Delta[f_1](x_0, x_1) + r \cdot \Delta[f_2](x_0, x_1)$.
- (29) $\Delta[f_1 - r f_2](x_0, x_1) = \Delta[f_1](x_0, x_1) - r \cdot \Delta[f_2](x_0, x_1)$.
- (30) $\Delta[r_1 f_1 - r_2 f_2](x_0, x_1) = r_1 \cdot \Delta[f_1](x_0, x_1) - r_2 \cdot \Delta[f_2](x_0, x_1)$.
- (31) $(\vec{\nabla}_h[f_1 f_2])(1)(x) = f_1(x) \cdot (\vec{\nabla}_h[f_2])(1)(x) + f_2(x-h) \cdot (\vec{\nabla}_h[f_1])(1)(x)$.
- (32) If x_0, x_1, x_2 are mutually different, then $\Delta[f](x_0, x_1, x_2) = \Delta[f](x_0, x_2, x_1)$.

In the sequel S is a sequence of real sequences.

We now state a number of propositions:

- (33) Suppose that for all natural numbers n, i such that $i \leq n$ holds $S(n)(i) = \binom{n}{i} \cdot (\vec{\nabla}_h[f_1])(i)(x) \cdot (\vec{\nabla}_h[f_2])(n-i)(x - i \cdot h)$. Then $(\vec{\nabla}_h[f_1 f_2])(1)(x) = \sum_{\kappa=0}^1 S(1)(\kappa)$ and $(\vec{\nabla}_h[f_1 f_2])(2)(x) = \sum_{\kappa=0}^2 S(2)(\kappa)$.
- (34) $(\vec{\delta}_h[f_1 f_2])(1)(x) = f_1(x + \frac{h}{2}) \cdot (\vec{\delta}_h[f_2])(1)(x) + f_2(x - \frac{h}{2}) \cdot (\vec{\delta}_h[f_1])(1)(x)$.
- (35) Suppose that for all natural numbers n, i such that $i \leq n$ holds $S(n)(i) = \binom{n}{i} \cdot (\vec{\delta}_h[f_1])(i)(x + (n-i) \cdot \frac{h}{2}) \cdot (\vec{\delta}_h[f_2])(n-i)(x - i \cdot \frac{h}{2})$. Then $(\vec{\delta}_h[f_1 f_2])(1)(x) = \sum_{\kappa=0}^1 S(1)(\kappa)$ and $(\vec{\delta}_h[f_1 f_2])(2)(x) = \sum_{\kappa=0}^2 S(2)(\kappa)$.
- (36) If for every x holds $f(x) = \sqrt{x}$ and $x_0 \neq x_1$ and $x_0 > 0$ and $x_1 > 0$, then $\Delta[f](x_0, x_1) = \frac{1}{\sqrt{x_0} + \sqrt{x_1}}$.

- (37) Suppose for every x holds $f(x) = \sqrt{x}$ and x_0, x_1, x_2 are mutually different and $x_0 > 0$ and $x_1 > 0$ and $x_2 > 0$. Then $\Delta[f](x_0, x_1, x_2) = \frac{1}{(\sqrt{x_0} + \sqrt{x_1}) \cdot (\sqrt{x_0} + \sqrt{x_2}) \cdot (\sqrt{x_1} + \sqrt{x_2})}$.
- (38) Suppose for every x holds $f(x) = \sqrt{x}$ and x_0, x_1, x_2, x_3 are mutually different and $x_0 > 0$ and $x_1 > 0$ and $x_2 > 0$ and $x_3 > 0$.
Then $\Delta[f](x_0, x_1, x_2, x_3) = \frac{\sqrt{x_0} + \sqrt{x_1} + \sqrt{x_2} + \sqrt{x_3}}{(\sqrt{x_0} + \sqrt{x_1}) \cdot (\sqrt{x_0} + \sqrt{x_2}) \cdot (\sqrt{x_0} + \sqrt{x_3}) \cdot (\sqrt{x_1} + \sqrt{x_2}) \cdot (\sqrt{x_1} + \sqrt{x_3}) \cdot (\sqrt{x_2} + \sqrt{x_3})}$.
- (39) If for every x holds $f(x) = \sqrt{x}$ and $x > 0$ and $x + h > 0$, then $(\Delta_h[f])(x) = \sqrt{x+h} - \sqrt{x}$.
- (40) If for every x holds $f(x) = \sqrt{x}$ and $x > 0$ and $x - h > 0$, then $(\nabla_h[f])(x) = \sqrt{x} - \sqrt{x-h}$.
- (41) If for every x holds $f(x) = \sqrt{x}$ and $x + \frac{h}{2} > 0$ and $x - \frac{h}{2} > 0$, then $(\delta_h[f])(x) = \sqrt{x + \frac{h}{2}} - \sqrt{x - \frac{h}{2}}$.
- (42) If for every x holds $f(x) = x^2$ and $x_0 \neq x_1$, then $\Delta[f](x_0, x_1) = x_0 + x_1$.
- (43) If for every x holds $f(x) = x^2$ and x_0, x_1, x_2 are mutually different, then $\Delta[f](x_0, x_1, x_2) = 1$.
- (44) If for every x holds $f(x) = x^2$ and x_0, x_1, x_2, x_3 are mutually different, then $\Delta[f](x_0, x_1, x_2, x_3) = 0$.
- (45) If for every x holds $f(x) = x^2$, then $(\Delta_h[f])(x) = 2 \cdot x \cdot h + h^2$.
- (46) If for every x holds $f(x) = x^2$, then $(\nabla_h[f])(x) = h \cdot (2 \cdot x - h)$.
- (47) If for every x holds $f(x) = x^2$, then $(\delta_h[f])(x) = 2 \cdot h \cdot x$.
- (48) If for every x holds $f(x) = \frac{k}{x^2}$ and $x_0 \neq x_1$ and $x_0 \neq 0$ and $x_1 \neq 0$, then $\Delta[f](x_0, x_1) = -\frac{k}{x_0 \cdot x_1} \cdot (\frac{1}{x_0} + \frac{1}{x_1})$.
- (49) Suppose for every x holds $f(x) = \frac{k}{x^2}$ and $x_0 \neq 0$ and $x_1 \neq 0$ and $x_2 \neq 0$ and x_0, x_1, x_2 are mutually different. Then $\Delta[f](x_0, x_1, x_2) = \frac{k}{x_0 \cdot x_1 \cdot x_2} \cdot (\frac{1}{x_0} + \frac{1}{x_1} + \frac{1}{x_2})$.
- (50) If for every x holds $f(x) = \frac{k}{x^2}$ and $x \neq 0$ and $x+h \neq 0$, then $(\Delta_h[f])(x) = \frac{(-k) \cdot h \cdot (2 \cdot x + h)}{(x^2 + h \cdot x)^2}$.
- (51) If for every x holds $f(x) = \frac{k}{x^2}$ and $x \neq 0$ and $x-h \neq 0$, then $(\nabla_h[f])(x) = \frac{(-k) \cdot h \cdot (2 \cdot x - h)}{(x^2 - x \cdot h)^2}$.
- (52) If for every x holds $f(x) = \frac{k}{x^2}$ and $x + \frac{h}{2} \neq 0$ and $x - \frac{h}{2} \neq 0$, then $(\delta_h[f])(x) = \frac{-2 \cdot h \cdot k \cdot x}{(x^2 - (\frac{h}{2})^2)^2}$.
- (53) $\Delta[(\text{the function sin}) (\text{the function sin}) (\text{the function sin})](x_0, x_1) = \frac{\frac{1}{2} \cdot (3 \cdot \cos(\frac{x_0+x_1}{2}) \cdot \sin(\frac{x_0-x_1}{2}) - \cos(\frac{3 \cdot (x_0+x_1)}{2}) \cdot \sin(\frac{3 \cdot (x_0-x_1)}{2}))}{x_0-x_1}$.
- (54) $(\Delta_h[(\text{the function sin}) (\text{the function sin}) (\text{the function sin})])(x) = \frac{1}{2} \cdot (3 \cdot \cos(\frac{2 \cdot x + h}{2}) \cdot \sin(\frac{h}{2}) - \cos(\frac{3 \cdot (2 \cdot x + h)}{2}) \cdot \sin(\frac{3 \cdot h}{2}))$.

- (55) $(\nabla_h[(\text{the function sin}) (\text{the function sin}) (\text{the function sin})])(x) = \frac{1}{2} \cdot (3 \cdot \cos(\frac{2 \cdot x - h}{2}) \cdot \sin(\frac{h}{2}) - \cos(\frac{3 \cdot (2 \cdot x - h)}{2}) \cdot \sin(\frac{3 \cdot h}{2}))$.
- (56) $(\delta_h[(\text{the function sin}) (\text{the function sin}) (\text{the function sin})])(x) = \frac{1}{2} \cdot (3 \cdot \cos x \cdot \sin(\frac{h}{2}) - \cos(3 \cdot x) \cdot \sin(\frac{3 \cdot h}{2}))$.
- (57) $\Delta[(\text{the function cos}) (\text{the function cos}) (\text{the function cos})](x_0, x_1) = -\frac{\frac{1}{2} \cdot (3 \cdot \sin(\frac{x_0 + x_1}{2}) \cdot \sin(\frac{x_0 - x_1}{2}) + \sin(\frac{3 \cdot x_0 + 3 \cdot x_1}{2}) \cdot \sin(\frac{3 \cdot x_0 - 3 \cdot x_1}{2}))}{x_0 - x_1}$.
- (58) $(\Delta_h[(\text{the function cos}) (\text{the function cos}) (\text{the function cos})])(x) = -\frac{1}{2} \cdot (3 \cdot \sin(\frac{2 \cdot x + h}{2}) \cdot \sin(\frac{h}{2}) + \sin(\frac{3 \cdot (2 \cdot x + h)}{2}) \cdot \sin(\frac{3 \cdot h}{2}))$.
- (59) $(\nabla_h[(\text{the function cos}) (\text{the function cos}) (\text{the function cos})])(x) = -\frac{1}{2} \cdot (3 \cdot \sin(\frac{2 \cdot x - h}{2}) \cdot \sin(\frac{h}{2}) + \sin(\frac{3 \cdot (2 \cdot x - h)}{2}) \cdot \sin(\frac{3 \cdot h}{2}))$.
- (60) $(\delta_h[(\text{the function cos}) (\text{the function cos}) (\text{the function cos})])(x) = -\frac{1}{2} \cdot (3 \cdot \sin x \cdot \sin(\frac{h}{2}) + \sin(3 \cdot x) \cdot \sin(\frac{3 \cdot h}{2}))$.
- (61) If for every x holds $f(x) = \frac{1}{\sin x}$ and $\sin x_0 \neq 0$ and $\sin x_1 \neq 0$, then $\Delta[f](x_0, x_1) = -\frac{2 \cdot (\sin x_1 - \sin x_0)}{\cos(x_0 + x_1) - \cos(x_0 - x_1)} \cdot \frac{1}{x_0 - x_1}$.
- (62) If for every x holds $f(x) = \frac{1}{\sin x}$ and $\sin x \neq 0$ and $\sin(x + h) \neq 0$, then $(\Delta_h[f])(x) = -\frac{2 \cdot (\sin x - \sin(x + h))}{\cos(2 \cdot x + h) - \cos h}$.
- (63) If for every x holds $f(x) = \frac{1}{\sin x}$ and $\sin x \neq 0$ and $\sin(x - h) \neq 0$, then $(\nabla_h[f])(x) = \frac{(-2) \cdot (\sin(x - h) - \sin x)}{\cos(2 \cdot x - h) - \cos h}$.
- (64) If for every x holds $f(x) = \frac{1}{\sin x}$ and $\sin(x + \frac{h}{2}) \neq 0$ and $\sin(x - \frac{h}{2}) \neq 0$, then $(\delta_h[f])(x) = -\frac{2 \cdot (\sin(x - \frac{h}{2}) - \sin(x + \frac{h}{2}))}{\cos(2 \cdot x) - \cos h}$.
- (65) If for every x holds $f(x) = \frac{1}{\cos x}$ and $x_0 \neq x_1$ and $\cos x_0 \neq 0$ and $\cos x_1 \neq 0$, then $\Delta[f](x_0, x_1) = \frac{2 \cdot (\cos x_1 - \cos x_0)}{\cos(x_0 + x_1) + \cos(x_0 - x_1)} \cdot \frac{1}{x_0 - x_1}$.
- (66) If for every x holds $f(x) = \frac{1}{\cos x}$ and $\cos x \neq 0$ and $\cos(x + h) \neq 0$, then $(\Delta_h[f])(x) = \frac{2 \cdot (\cos x - \cos(x + h))}{\cos(2 \cdot x + h) + \cos h}$.
- (67) If for every x holds $f(x) = \frac{1}{\cos x}$ and $\cos x \neq 0$ and $\cos(x - h) \neq 0$, then $(\nabla_h[f])(x) = \frac{2 \cdot (\cos(x - h) - \cos x)}{\cos(2 \cdot x - h) + \cos h}$.
- (68) If for every x holds $f(x) = \frac{1}{\cos x}$ and $\cos(x + \frac{h}{2}) \neq 0$ and $\cos(x - \frac{h}{2}) \neq 0$, then $(\delta_h[f])(x) = \frac{2 \cdot (\cos(x - \frac{h}{2}) - \cos(x + \frac{h}{2}))}{\cos(2 \cdot x) + \cos h}$.
- (69) Suppose for every x holds $f(x) = \frac{1}{(\sin x)^2}$ and $x_0 \neq x_1$ and $\sin x_0 \neq 0$ and $\sin x_1 \neq 0$. Then $\Delta[f](x_0, x_1) = \frac{16 \cdot \cos(\frac{x_1 + x_0}{2}) \cdot \sin(\frac{x_1 - x_0}{2}) \cdot \cos(\frac{x_1 - x_0}{2}) \cdot \sin(\frac{x_1 + x_0}{2})}{(\cos(x_0 + x_1) - \cos(x_0 - x_1))^2 \cdot (x_0 - x_1)}$.
- (70) If for every x holds $f(x) = \frac{1}{(\sin x)^2}$ and $\sin x \neq 0$ and $\sin(x + h) \neq 0$, then $(\Delta_h[f])(x) = \frac{16 \cdot \cos(\frac{2 \cdot x + h}{2}) \cdot \sin(\frac{-h}{2}) \cdot \cos(\frac{-h}{2}) \cdot \sin(\frac{2 \cdot x + h}{2})}{(\cos(2 \cdot x + h) - \cos h)^2}$.
- (71) If for every x holds $f(x) = \frac{1}{(\sin x)^2}$ and $\sin x \neq 0$ and $\sin(x - h) \neq 0$, then

- $(\nabla_h[f])(x) = \frac{16 \cdot \cos(\frac{2 \cdot x - h}{2}) \cdot \sin(\frac{-h}{2}) \cdot \cos(\frac{-h}{2}) \cdot \sin(\frac{2 \cdot x - h}{2})}{(\cos(2 \cdot x - h) - \cos h)^2}$.
- (72) If for every x holds $f(x) = \frac{1}{(\sin x)^2}$ and $\sin(x + \frac{h}{2}) \neq 0$ and $\sin(x - \frac{h}{2}) \neq 0$, then $(\delta_h[f])(x) = \frac{16 \cdot \cos x \cdot \sin(\frac{-h}{2}) \cdot \cos(\frac{-h}{2}) \cdot \sin x}{(\cos(2 \cdot x) - \cos h)^2}$.
- (73) Suppose for every x holds $f(x) = \frac{1}{(\cos x)^2}$ and $x_0 \neq x_1$ and $\cos x_0 \neq 0$ and $\cos x_1 \neq 0$. Then $\Delta[f](x_0, x_1) = \frac{(-16) \cdot \sin(\frac{x_1 + x_0}{2}) \cdot \sin(\frac{x_1 - x_0}{2}) \cdot \cos(\frac{x_1 + x_0}{2}) \cdot \cos(\frac{x_1 - x_0}{2})}{(\cos(x_0 + x_1) + \cos(x_0 - x_1))^2 \cdot x_0 - x_1}$.
- (74) If for every x holds $f(x) = \frac{1}{(\cos x)^2}$ and $\cos x \neq 0$ and $\cos(x + h) \neq 0$, then $(\Delta_h[f])(x) = \frac{(-16) \cdot \sin(\frac{2 \cdot x + h}{2}) \cdot \sin(\frac{-h}{2}) \cdot \cos(\frac{2 \cdot x + h}{2}) \cdot \cos(\frac{-h}{2})}{(\cos(2 \cdot x + h) + \cos h)^2}$.
- (75) If for every x holds $f(x) = \frac{1}{(\cos x)^2}$ and $\cos x \neq 0$ and $\cos(x - h) \neq 0$, then $(\nabla_h[f])(x) = \frac{(-16) \cdot \sin(\frac{2 \cdot x - h}{2}) \cdot \sin(\frac{-h}{2}) \cdot \cos(\frac{2 \cdot x - h}{2}) \cdot \cos(\frac{-h}{2})}{(\cos(2 \cdot x - h) + \cos h)^2}$.
- (76) If for every x holds $f(x) = \frac{1}{(\cos x)^2}$ and $\cos(x + \frac{h}{2}) \neq 0$ and $\cos(x - \frac{h}{2}) \neq 0$, then $(\delta_h[f])(x) = \frac{(-16) \cdot \sin x \cdot \sin(\frac{-h}{2}) \cdot \cos x \cdot \cos(\frac{-h}{2})}{(\cos(2 \cdot x) + \cos h)^2}$.
- (77) Suppose $x_0 \in \text{dom}(\text{the function tan})$ and $x_1 \in \text{dom}(\text{the function tan})$. Then $\Delta[(\text{the function tan}) (\text{the function sin})](x_0, x_1) = \frac{(\frac{1}{\cos x_0} - \cos x_0 - \frac{1}{\cos x_1}) + \cos x_1}{x_0 - x_1}$.
- (78) Suppose that
- (i) for every x holds $f(x) = ((\text{the function tan}) (\text{the function sin}))(x)$,
 - (ii) $x \in \text{dom}(\text{the function tan})$, and
 - (iii) $x + h \in \text{dom}(\text{the function tan})$.
- Then $(\Delta_h[f])(x) = (\frac{1}{\cos(x+h)} - \cos(x+h) - \frac{1}{\cos x}) + \cos x$.
- (79) Suppose that
- (i) for every x holds $f(x) = ((\text{the function tan}) (\text{the function sin}))(x)$,
 - (ii) $x \in \text{dom}(\text{the function tan})$, and
 - (iii) $x - h \in \text{dom}(\text{the function tan})$.
- Then $(\nabla_h[f])(x) = (\frac{1}{\cos x} - \cos x - \frac{1}{\cos(x-h)}) + \cos(x-h)$.
- (80) Suppose that
- (i) for every x holds $f(x) = ((\text{the function tan}) (\text{the function sin}))(x)$,
 - (ii) $x + \frac{h}{2} \in \text{dom}(\text{the function tan})$, and
 - (iii) $x - \frac{h}{2} \in \text{dom}(\text{the function tan})$.
- Then $(\delta_h[f])(x) = (\frac{1}{\cos(x+\frac{h}{2})} - \cos(x+\frac{h}{2}) - \frac{1}{\cos(x-\frac{h}{2})}) + \cos(x-\frac{h}{2})$.
- (81) Suppose for every x holds $f(x) = ((\text{the function tan}) (\text{the function cos}))(x)$ and $x_0 \in \text{dom}(\text{the function tan})$ and $x_1 \in \text{dom}(\text{the function tan})$. Then $\Delta[f](x_0, x_1) = \frac{\sin x_0 - \sin x_1}{x_0 - x_1}$.
- (82) Suppose that
- (i) for every x holds $f(x) = ((\text{the function tan}) (\text{the function cos}))(x)$,
 - (ii) $x \in \text{dom}(\text{the function tan})$, and

(iii) $x + h \in \text{dom}(\text{the function tan})$.

$$\text{Then } (\Delta_h[f])(x) = \sin(x + h) - \sin x.$$

(83) Suppose that

(i) for every x holds $f(x) = ((\text{the function tan}) (\text{the function cos}))(x)$,

(ii) $x \in \text{dom}(\text{the function tan})$, and

(iii) $x - h \in \text{dom}(\text{the function tan})$.

$$\text{Then } (\nabla_h[f])(x) = \sin x - \sin(x - h).$$

(84) Suppose that

(i) for every x holds $f(x) = ((\text{the function tan}) (\text{the function cos}))(x)$,

(ii) $x + \frac{h}{2} \in \text{dom}(\text{the function tan})$, and

(iii) $x - \frac{h}{2} \in \text{dom}(\text{the function tan})$.

$$\text{Then } (\delta_h[f])(x) = \sin(x + \frac{h}{2}) - \sin(x - \frac{h}{2}).$$

(85) Suppose for every x holds $f(x) = ((\text{the function cot}) (\text{the function cos}))(x)$ and $x_0 \in \text{dom}(\text{the function cot})$ and $x_1 \in \text{dom}(\text{the function cot})$.

$$\text{Then } \Delta[f](x_0, x_1) = \frac{(\frac{1}{\sin x_0} - \sin x_0 - \frac{1}{\sin x_1}) + \sin x_1}{x_0 - x_1}.$$

(86) Suppose that

(i) for every x holds $f(x) = ((\text{the function cot}) (\text{the function cos}))(x)$,

(ii) $x \in \text{dom}(\text{the function cot})$, and

(iii) $x + h \in \text{dom}(\text{the function cot})$.

$$\text{Then } (\Delta_h[f])(x) = (\frac{1}{\sin(x+h)} - \sin(x+h) - \frac{1}{\sin x}) + \sin x.$$

(87) Suppose that

(i) for every x holds $f(x) = ((\text{the function cot}) (\text{the function cos}))(x)$,

(ii) $x \in \text{dom}(\text{the function cot})$, and

(iii) $x - h \in \text{dom}(\text{the function cot})$.

$$\text{Then } (\nabla_h[f])(x) = (\frac{1}{\sin x} - \sin x - \frac{1}{\sin(x-h)}) + \sin(x-h).$$

(88) Suppose that

(i) for every x holds $f(x) = ((\text{the function cot}) (\text{the function cos}))(x)$,

(ii) $x + \frac{h}{2} \in \text{dom}(\text{the function cot})$, and

(iii) $x - \frac{h}{2} \in \text{dom}(\text{the function cot})$.

$$\text{Then } (\delta_h[f])(x) = (\frac{1}{\sin(x+\frac{h}{2})} - \sin(x+\frac{h}{2}) - \frac{1}{\sin(x-\frac{h}{2})}) + \sin(x-\frac{h}{2}).$$

(89) Suppose for every x holds $f(x) = ((\text{the function cot}) (\text{the function sin}))(x)$ and $x_0 \in \text{dom}(\text{the function cot})$ and $x_1 \in \text{dom}(\text{the function cot})$.

$$\text{Then } \Delta[f](x_0, x_1) = \frac{\cos x_0 - \cos x_1}{x_0 - x_1}.$$

(90) Suppose that

(i) for every x holds $f(x) = ((\text{the function cot}) (\text{the function sin}))(x)$,

(ii) $x \in \text{dom}(\text{the function cot})$, and

(iii) $x + h \in \text{dom}(\text{the function cot})$.

$$\text{Then } (\Delta_h[f])(x) = \cos(x+h) - \cos x.$$

(91) Suppose that

(i) for every x holds $f(x) = ((\text{the function cot}) (\text{the function sin}))(x)$,

- (ii) $x \in \text{dom}(\text{the function cot})$, and
 - (iii) $x - h \in \text{dom}(\text{the function cot})$.
- Then $(\nabla_h[f])(x) = \cos x - \cos(x - h)$.

(92) Suppose that

- (i) for every x holds $f(x) = ((\text{the function cot}) (\text{the function sin}))(x)$,
 - (ii) $x + \frac{h}{2} \in \text{dom}(\text{the function cot})$, and
 - (iii) $x - \frac{h}{2} \in \text{dom}(\text{the function cot})$.
- Then $(\delta_h[f])(x) = \cos(x + \frac{h}{2}) - \cos(x - \frac{h}{2})$.

(93) Suppose for every x holds $f(x) = ((\text{the function tan}) (\text{the function tan}))(x)$ and $x_0 \in \text{dom}(\text{the function tan})$ and $x_1 \in \text{dom}(\text{the function tan})$. Then $\Delta[f](x_0, x_1) = \frac{(\cos x_1)^2 - (\cos x_0)^2}{(\cos x_0 \cdot \cos x_1)^2 \cdot (x_0 - x_1)}$.

(94) Suppose that

- (i) for every x holds $f(x) = ((\text{the function tan}) (\text{the function tan}))(x)$,
- (ii) $x \in \text{dom}(\text{the function tan})$, and
- (iii) $x + h \in \text{dom}(\text{the function tan})$.

$$\text{Then } (\Delta_h[f])(x) = -\frac{\frac{1}{2} \cdot (\cos(2 \cdot (x+h)) - \cos(2 \cdot x))}{(\cos(x+h) \cdot \cos x)^2}.$$

(95) Suppose that

- (i) for every x holds $f(x) = ((\text{the function tan}) (\text{the function tan}))(x)$,
- (ii) $x \in \text{dom}(\text{the function tan})$, and
- (iii) $x - h \in \text{dom}(\text{the function tan})$.

$$\text{Then } (\nabla_h[f])(x) = -\frac{\frac{1}{2} \cdot (\cos(2 \cdot x) - \cos(2 \cdot (h-x)))}{(\cos x \cdot \cos(x-h))^2}.$$

(96) Suppose that

- (i) for every x holds $f(x) = ((\text{the function tan}) (\text{the function tan}))(x)$,
- (ii) $x + \frac{h}{2} \in \text{dom}(\text{the function tan})$, and
- (iii) $x - \frac{h}{2} \in \text{dom}(\text{the function tan})$.

$$\text{Then } (\delta_h[f])(x) = -\frac{\frac{1}{2} \cdot (\cos(h+2 \cdot x) - \cos(h-2 \cdot x))}{(\cos(x+\frac{h}{2}) \cdot \cos(x-\frac{h}{2}))^2}.$$

REFERENCES

- [1] Grzegorz Bancerek. The fundamental properties of natural numbers. *Formalized Mathematics*, 1(1):41–46, 1990.
- [2] Czesław Byliński. Functions from a set to a set. *Formalized Mathematics*, 1(1):153–164, 1990.
- [3] Czesław Byliński. Some basic properties of sets. *Formalized Mathematics*, 1(1):47–53, 1990.
- [4] Krzysztof Hryniewiecki. Basic properties of real numbers. *Formalized Mathematics*, 1(1):35–40, 1990.
- [5] Jarosław Kotowicz. Real sequences and basic operations on them. *Formalized Mathematics*, 1(2):269–272, 1990.
- [6] Bo Li, Yan Zhang, and Xiquan Liang. Difference and difference quotient. *Formalized Mathematics*, 14(3):115–119, 2006, doi:10.2478/v10037-006-0014-z.
- [7] Beata Perkowska. Functional sequence from a domain to a domain. *Formalized Mathematics*, 3(1):17–21, 1992.
- [8] Konrad Raczkowski and Andrzej Nędzusiak. Series. *Formalized Mathematics*, 2(4):449–452, 1991.

- [9] Andrzej Trybulec and Czesław Byliński. Some properties of real numbers. *Formalized Mathematics*, 1(3):445–449, 1990.
- [10] Zinaida Trybulec. Properties of subsets. *Formalized Mathematics*, 1(1):67–71, 1990.
- [11] Edmund Woronowicz. Relations defined on sets. *Formalized Mathematics*, 1(1):181–186, 1990.
- [12] Yuguang Yang and Yasunari Shidama. Trigonometric functions and existence of circle ratio. *Formalized Mathematics*, 7(2):255–263, 1998.

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