

## COMPLEX NUMBERS

### DEFINITION

The Imaginary Unit  $i = \sqrt{-1}$  and  $i^2 = -1$   
 Complex Number  $a + bi$  (where  $a, b \in \mathbb{R}$ )  
 Real part  $a$  and Imaginary part  $b$   
 If  $a = 0$  or  $b = 0$ , then it is a real number.

Conjugate Complex Number  $a - bi$  and  $a + bi$

Modulus (absolute value)  $|a + bi| = \sqrt{a^2 + b^2}$

Argument (angle)  $\theta$  (where  $a > 0$  and  $b > 0$ )

Complex Number  $a + bi$  (where  $a, b \in \mathbb{R}$ )

### ALGEBRA

Addition  $(a + bi) + (c + di) = (a + c) + (b + d)i$

Subtraction  $(a + bi) - (c + di) = (a - c) + (b - d)i$

Multiplication  $(a + bi)(c + di) = (ac - bd) + (ad + bc)i$

Multiplication of conjugates  $(a + bi)(a - bi) = a^2 + b^2$

Multiplication of Polar Form  $(r_1 \angle \theta_1)(r_2 \angle \theta_2) = r_1 r_2 \angle \theta_1 + \theta_2$

Division  $\frac{a + bi}{c + di} = \frac{(a + bi)(c - di)}{(c + di)(c - di)} = \frac{(ac + bd) + (bc - ad)i}{c^2 + d^2}$

Division of Polar Form  $\frac{r_1 \angle \theta_1}{r_2 \angle \theta_2} = \frac{r_1}{r_2} \angle \theta_1 - \theta_2$

Complex Plane (Argand Diagram)

### EXAMPLES

Example 1

$$(2 + 3i) + (4 - 5i) = 6 - 2i$$

$$(2 + 3i) - (4 - 5i) = -2 + 8i$$

$$(2 + 3i)(4 - 5i) = 8 - 10i + 12i - 15i^2 = 8 - 10i + 12i + 15 = 23 + 2i$$

Example 2

$$\frac{2 + 3i}{4 - 5i} = \frac{(2 + 3i)(4 + 5i)}{(4 - 5i)(4 + 5i)} = \frac{8 + 10i + 12i + 15i^2}{16 - 25i^2} = \frac{-7 + 22i}{41}$$

$$\frac{2 + 3i}{4 - 5i} = \frac{2 + 3i}{4 - 5i} \cdot \frac{4 + 5i}{4 + 5i} = \frac{(2 + 3i)(4 + 5i)}{16 - 25i^2} = \frac{-7 + 22i}{41}$$

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### ALGEBRA

$$(2 + 3i)^2 = 4 + 12i + 9i^2 = 4 + 12i - 9 = -5 + 12i$$

$$(2 + 3i)^3 = (2 + 3i)(2 + 3i)^2 = (2 + 3i)(-5 + 12i) = -10 + 24i - 15i + 36i^2 = -10 + 9i - 36 = -46 + 9i$$

$$(2 + 3i)^4 = (2 + 3i)^2(2 + 3i)^2 = (-5 + 12i)(-5 + 12i) = 25 - 120i + 144i^2 = 25 - 120i - 144 = -119 - 120i$$

$$(2 + 3i)^5 = (2 + 3i)^4(2 + 3i) = (-119 - 120i)(2 + 3i) = -238 - 357i - 240i - 360i^2 = -238 - 597i + 360 = 122 - 597i$$

$$(2 + 3i)^6 = (2 + 3i)^5(2 + 3i) = (122 - 597i)(2 + 3i) = 244 - 1791i - 1194i - 1791i^2 = 244 - 2985i + 1791 = 2035 - 2985i$$

## POLYNOMIAL EQUATIONS

### DEFINITION

Polynomial Equation  $a_n x^n + a_{n-1} x^{n-1} + \dots + a_1 x + a_0 = 0$

where  $a_n \neq 0$  (degree  $n$ )

Roots  $r_1, r_2, \dots, r_n$  of  $a_n x^n + a_{n-1} x^{n-1} + \dots + a_1 x + a_0 = 0$

Sum of roots  $r_1 + r_2 + \dots + r_n = -\frac{a_{n-1}}{a_n}$

Product of roots  $r_1 r_2 \dots r_n = \frac{a_0}{a_n}$

Sum of squares of roots  $r_1^2 + r_2^2 + \dots + r_n^2 = \left(\frac{a_{n-1}}{a_n}\right)^2 - 2\frac{a_{n-2}}{a_n}$

Sum of cubes of roots  $r_1^3 + r_2^3 + \dots + r_n^3 = \left(\frac{a_{n-1}}{a_n}\right)^3 - 3\frac{a_{n-1}a_{n-2}}{a_n^2} + 3\frac{a_{n-3}}{a_n}$

Sum of fourth powers of roots  $r_1^4 + r_2^4 + \dots + r_n^4 = \left(\frac{a_{n-1}}{a_n}\right)^4 - 4\frac{a_{n-1}a_{n-2}}{a_n^2} + 6\frac{a_{n-2}^2}{a_n^2} - 4\frac{a_{n-3}a_{n-1}}{a_n^2} + 4\frac{a_{n-4}}{a_n}$

Sum of fifth powers of roots  $r_1^5 + r_2^5 + \dots + r_n^5 = \left(\frac{a_{n-1}}{a_n}\right)^5 - 5\frac{a_{n-1}a_{n-2}}{a_n^2} + 10\frac{a_{n-2}^2}{a_n^2} - 10\frac{a_{n-3}a_{n-1}}{a_n^2} + 10\frac{a_{n-4}a_{n-2}}{a_n^2} - 5\frac{a_{n-5}}{a_n}$

Sum of sixth powers of roots  $r_1^6 + r_2^6 + \dots + r_n^6 = \left(\frac{a_{n-1}}{a_n}\right)^6 - 6\frac{a_{n-1}a_{n-2}}{a_n^2} + 15\frac{a_{n-2}^2}{a_n^2} - 20\frac{a_{n-3}a_{n-1}}{a_n^2} + 15\frac{a_{n-4}a_{n-2}}{a_n^2} - 6\frac{a_{n-5}a_{n-1}}{a_n^2} + 6\frac{a_{n-6}}{a_n}$

Sum of seventh powers of roots  $r_1^7 + r_2^7 + \dots + r_n^7 = \left(\frac{a_{n-1}}{a_n}\right)^7 - 7\frac{a_{n-1}a_{n-2}}{a_n^2} + 21\frac{a_{n-2}^2}{a_n^2} - 35\frac{a_{n-3}a_{n-1}}{a_n^2} + 35\frac{a_{n-4}a_{n-2}}{a_n^2} - 21\frac{a_{n-5}a_{n-1}}{a_n^2} + 7\frac{a_{n-6}a_{n-2}}{a_n^2} - 7\frac{a_{n-7}}{a_n}$

Sum of eighth powers of roots  $r_1^8 + r_2^8 + \dots + r_n^8 = \left(\frac{a_{n-1}}{a_n}\right)^8 - 8\frac{a_{n-1}a_{n-2}}{a_n^2} + 28\frac{a_{n-2}^2}{a_n^2} - 56\frac{a_{n-3}a_{n-1}}{a_n^2} + 70\frac{a_{n-4}a_{n-2}}{a_n^2} - 56\frac{a_{n-5}a_{n-1}}{a_n^2} + 28\frac{a_{n-6}a_{n-2}}{a_n^2} - 8\frac{a_{n-7}a_{n-1}}{a_n^2} + 8\frac{a_{n-8}}{a_n}$

Sum of ninth powers of roots  $r_1^9 + r_2^9 + \dots + r_n^9 = \left(\frac{a_{n-1}}{a_n}\right)^9 - 9\frac{a_{n-1}a_{n-2}}{a_n^2} + 36\frac{a_{n-2}^2}{a_n^2} - 81\frac{a_{n-3}a_{n-1}}{a_n^2} + 126\frac{a_{n-4}a_{n-2}}{a_n^2} - 126\frac{a_{n-5}a_{n-1}}{a_n^2} + 81\frac{a_{n-6}a_{n-2}}{a_n^2} - 27\frac{a_{n-7}a_{n-1}}{a_n^2} + 9\frac{a_{n-8}a_{n-2}}{a_n^2} - 9\frac{a_{n-9}}{a_n}$

Sum of tenth powers of roots  $r_1^{10} + r_2^{10} + \dots + r_n^{10} = \left(\frac{a_{n-1}}{a_n}\right)^{10} - 10\frac{a_{n-1}a_{n-2}}{a_n^2} + 45\frac{a_{n-2}^2}{a_n^2} - 120\frac{a_{n-3}a_{n-1}}{a_n^2} + 225\frac{a_{n-4}a_{n-2}}{a_n^2} - 270\frac{a_{n-5}a_{n-1}}{a_n^2} + 135\frac{a_{n-6}a_{n-2}}{a_n^2} - 54\frac{a_{n-7}a_{n-1}}{a_n^2} + 10\frac{a_{n-8}a_{n-2}}{a_n^2} - 10\frac{a_{n-9}}{a_n}$

Sum of eleventh powers of roots  $r_1^{11} + r_2^{11} + \dots + r_n^{11} = \left(\frac{a_{n-1}}{a_n}\right)^{11} - 11\frac{a_{n-1}a_{n-2}}{a_n^2} + 55\frac{a_{n-2}^2}{a_n^2} - 165\frac{a_{n-3}a_{n-1}}{a_n^2} + 330\frac{a_{n-4}a_{n-2}}{a_n^2} - 462\frac{a_{n-5}a_{n-1}}{a_n^2} + 330\frac{a_{n-6}a_{n-2}}{a_n^2} - 165\frac{a_{n-7}a_{n-1}}{a_n^2} + 55\frac{a_{n-8}a_{n-2}}{a_n^2} - 11\frac{a_{n-9}}{a_n}$

Sum of twelfth powers of roots  $r_1^{12} + r_2^{12} + \dots + r_n^{12} = \left(\frac{a_{n-1}}{a_n}\right)^{12} - 12\frac{a_{n-1}a_{n-2}}{a_n^2} + 66\frac{a_{n-2}^2}{a_n^2} - 220\frac{a_{n-3}a_{n-1}}{a_n^2} + 528\frac{a_{n-4}a_{n-2}}{a_n^2} - 858\frac{a_{n-5}a_{n-1}}{a_n^2} + 660\frac{a_{n-6}a_{n-2}}{a_n^2} - 330\frac{a_{n-7}a_{n-1}}{a_n^2} + 110\frac{a_{n-8}a_{n-2}}{a_n^2} - 12\frac{a_{n-9}}{a_n}$

Sum of thirteenth powers of roots  $r_1^{13} + r_2^{13} + \dots + r_n^{13} = \left(\frac{a_{n-1}}{a_n}\right)^{13} - 13\frac{a_{n-1}a_{n-2}}{a_n^2} + 78\frac{a_{n-2}^2}{a_n^2} - 286\frac{a_{n-3}a_{n-1}}{a_n^2} + 728\frac{a_{n-4}a_{n-2}}{a_n^2} - 1430\frac{a_{n-5}a_{n-1}}{a_n^2} + 1001\frac{a_{n-6}a_{n-2}}{a_n^2} - 572\frac{a_{n-7}a_{n-1}}{a_n^2} + 143\frac{a_{n-8}a_{n-2}}{a_n^2} - 13\frac{a_{n-9}}{a_n}$

Sum of fourteenth powers of roots  $r_1^{14} + r_2^{14} + \dots + r_n^{14} = \left(\frac{a_{n-1}}{a_n}\right)^{14} - 14\frac{a_{n-1}a_{n-2}}{a_n^2} + 91\frac{a_{n-2}^2}{a_n^2} - 364\frac{a_{n-3}a_{n-1}}{a_n^2} + 1001\frac{a_{n-4}a_{n-2}}{a_n^2} - 2002\frac{a_{n-5}a_{n-1}}{a_n^2} + 1430\frac{a_{n-6}a_{n-2}}{a_n^2} - 728\frac{a_{n-7}a_{n-1}}{a_n^2} + 182\frac{a_{n-8}a_{n-2}}{a_n^2} - 14\frac{a_{n-9}}{a_n}$

Sum of fifteenth powers of roots  $r_1^{15} + r_2^{15} + \dots + r_n^{15} = \left(\frac{a_{n-1}}{a_n}\right)^{15} - 15\frac{a_{n-1}a_{n-2}}{a_n^2} + 105\frac{a_{n-2}^2}{a_n^2} - 429\frac{a_{n-3}a_{n-1}}{a_n^2} + 1287\frac{a_{n-4}a_{n-2}}{a_n^2} - 2730\frac{a_{n-5}a_{n-1}}{a_n^2} + 2002\frac{a_{n-6}a_{n-2}}{a_n^2} - 1001\frac{a_{n-7}a_{n-1}}{a_n^2} + 210\frac{a_{n-8}a_{n-2}}{a_n^2} - 15\frac{a_{n-9}}{a_n}$

Sum of sixteenth powers of roots  $r_1^{16} + r_2^{16} + \dots + r_n^{16} = \left(\frac{a_{n-1}}{a_n}\right)^{16} - 16\frac{a_{n-1}a_{n-2}}{a_n^2} + 120\frac{a_{n-2}^2}{a_n^2} - 520\frac{a_{n-3}a_{n-1}}{a_n^2} + 1632\frac{a_{n-4}a_{n-2}}{a_n^2} - 3696\frac{a_{n-5}a_{n-1}}{a_n^2} + 2730\frac{a_{n-6}a_{n-2}}{a_n^2} - 1287\frac{a_{n-7}a_{n-1}}{a_n^2} + 273\frac{a_{n-8}a_{n-2}}{a_n^2} - 16\frac{a_{n-9}}{a_n}$

Sum of seventeenth powers of roots  $r_1^{17} + r_2^{17} + \dots + r_n^{17} = \left(\frac{a_{n-1}}{a_n}\right)^{17} - 17\frac{a_{n-1}a_{n-2}}{a_n^2} + 136\frac{a_{n-2}^2}{a_n^2} - 595\frac{a_{n-3}a_{n-1}}{a_n^2} + 1965\frac{a_{n-4}a_{n-2}}{a_n^2} - 4618\frac{a_{n-5}a_{n-1}}{a_n^2} + 3234\frac{a_{n-6}a_{n-2}}{a_n^2} - 1540\frac{a_{n-7}a_{n-1}}{a_n^2} + 323\frac{a_{n-8}a_{n-2}}{a_n^2} - 17\frac{a_{n-9}}{a_n}$

Sum of eighteenth powers of roots  $r_1^{18} + r_2^{18} + \dots + r_n^{18} = \left(\frac{a_{n-1}}{a_n}\right)^{18} - 18\frac{a_{n-1}a_{n-2}}{a_n^2} + 153\frac{a_{n-2}^2}{a_n^2} - 648\frac{a_{n-3}a_{n-1}}{a_n^2} + 2232\frac{a_{n-4}a_{n-2}}{a_n^2} - 5400\frac{a_{n-5}a_{n-1}}{a_n^2} + 3960\frac{a_{n-6}a_{n-2}}{a_n^2} - 1848\frac{a_{n-7}a_{n-1}}{a_n^2} + 396\frac{a_{n-8}a_{n-2}}{a_n^2} - 18\frac{a_{n-9}}{a_n}$

Sum of nineteenth powers of roots  $r_1^{19} + r_2^{19} + \dots + r_n^{19} = \left(\frac{a_{n-1}}{a_n}\right)^{19} - 19\frac{a_{n-1}a_{n-2}}{a_n^2} + 171\frac{a_{n-2}^2}{a_n^2} - 722\frac{a_{n-3}a_{n-1}}{a_n^2} + 2529\frac{a_{n-4}a_{n-2}}{a_n^2} - 6138\frac{a_{n-5}a_{n-1}}{a_n^2} + 4354\frac{a_{n-6}a_{n-2}}{a_n^2} - 2145\frac{a_{n-7}a_{n-1}}{a_n^2} + 435\frac{a_{n-8}a_{n-2}}{a_n^2} - 19\frac{a_{n-9}}{a_n}$

Sum of twentieth powers of roots  $r_1^{20} + r_2^{20} + \dots + r_n^{20} = \left(\frac{a_{n-1}}{a_n}\right)^{20} - 20\frac{a_{n-1}a_{n-2}}{a_n^2} + 190\frac{a_{n-2}^2}{a_n^2} - 800\frac{a_{n-3}a_{n-1}}{a_n^2} + 2880\frac{a_{n-4}a_{n-2}}{a_n^2} - 7200\frac{a_{n-5}a_{n-1}}{a_n^2} + 5040\frac{a_{n-6}a_{n-2}}{a_n^2} - 2430\frac{a_{n-7}a_{n-1}}{a_n^2} + 480\frac{a_{n-8}a_{n-2}}{a_n^2} - 20\frac{a_{n-9}}{a_n}$

Sum of twenty-first powers of roots  $r_1^{21} + r_2^{21} + \dots + r_n^{21} = \left(\frac{a_{n-1}}{a_n}\right)^{21} - 21\frac{a_{n-1}a_{n-2}}{a_n^2} + 210\frac{a_{n-2}^2}{a_n^2} - 882\frac{a_{n-3}a_{n-1}}{a_n^2} + 3150\frac{a_{n-4}a_{n-2}}{a_n^2} - 7938\frac{a_{n-5}a_{n-1}}{a_n^2} + 5670\frac{a_{n-6}a_{n-2}}{a_n^2} - 2772\frac{a_{n-7}a_{n-1}}{a_n^2} + 567\frac{a_{n-8}a_{n-2}}{a_n^2} - 21\frac{a_{n-9}}{a_n}$

Sum of twenty-second powers of roots  $r_1^{22} + r_2^{22} + \dots + r_n^{22} = \left(\frac{a_{n-1}}{a_n}\right)^{22} - 22\frac{a_{n-1}a_{n-2}}{a_n^2} + 231\frac{a_{n-2}^2}{a_n^2} - 924\frac{a_{n-3}a_{n-1}}{a_n^2} + 3360\frac{a_{n-4}a_{n-2}}{a_n^2} - 8400\frac{a_{n-5}a_{n-1}}{a_n^2} + 5940\frac{a_{n-6}a_{n-2}}{a_n^2} - 2860\frac{a_{n-7}a_{n-1}}{a_n^2} + 594\frac{a_{n-8}a_{n-2}}{a_n^2} - 22\frac{a_{n-9}}{a_n}$

Sum of twenty-third powers of roots  $r_1^{23} + r_2^{23} + \dots + r_n^{23} = \left(\frac{a_{n-1}}{a_n}\right)^{23} - 23\frac{a_{n-1}a_{n-2}}{a_n^2} + 253\frac{a_{n-2}^2}{a_n^2} - 989\frac{a_{n-3}a_{n-1}}{a_n^2} + 3651\frac{a_{n-4}a_{n-2}}{a_n^2} - 9009\frac{a_{n-5}a_{n-1}}{a_n^2} + 6351\frac{a_{n-6}a_{n-2}}{a_n^2} - 3003\frac{a_{n-7}a_{n-1}}{a_n^2} + 635\frac{a_{n-8}a_{n-2}}{a_n^2} - 23\frac{a_{n-9}}{a_n}$

Sum of twenty-four powers of roots  $r_1^{24} + r_2^{24} + \dots + r_n^{24} = \left(\frac{a_{n-1}}{a_n}\right)^{24} - 24\frac{a_{n-1}a_{n-2}}{a_n^2} + 276\frac{a_{n-2}^2}{a_n^2} - 1056\frac{a_{n-3}a_{n-1}}{a_n^2} + 3960\frac{a_{n-4}a_{n-2}}{a_n^2} - 9720\frac{a_{n-5}a_{n-1}}{a_n^2} + 6840\frac{a_{n-6}a_{n-2}}{a_n^2} - 3240\frac{a_{n-7}a_{n-1}}{a_n^2} + 684\frac{a_{n-8}a_{n-2}}{a_n^2} - 24\frac{a_{n-9}}{a_n}$

Sum of twenty-five powers of roots  $r_1^{25} + r_2^{25} + \dots + r_n^{25} = \left(\frac{a_{n-1}}{a_n}\right)^{25} - 25\frac{a_{n-1}a_{n-2}}{a_n^2} + 300\frac{a_{n-2}^2}{a_n^2} - 1125\frac{a_{n-3}a_{n-1}}{a_n^2} + 4275\frac{a_{n-4}a_{n-2}}{a_n^2} - 10395\frac{a_{n-5}a_{n-1}}{a_n^2} + 7290\frac{a_{n-6}a_{n-2}}{a_n^2} - 3465\frac{a_{n-7}a_{n-1}}{a_n^2} + 729\frac{a_{n-8}a_{n-2}}{a_n^2} - 25\frac{a_{n-9}}{a_n}$

Sum of twenty-six powers of roots  $r_1^{26} + r_2^{26} + \dots + r_n^{26} = \left(\frac{a_{n-1}}{a_n}\right)^{26} - 26\frac{a_{n-1}a_{n-2}}{a_n^2} + 326\frac{a_{n-2}^2}{a_n^2} - 1202\frac{a_{n-3}a_{n-1}}{a_n^2} + 4598\frac{a_{n-4}a_{n-2}}{a_n^2} - 11180\frac{a_{n-5}a_{n-1}}{a_n^2} + 7854\frac{a_{n-6}a_{n-2}}{a_n^2} - 3718\frac{a_{n-7}a_{n-1}}{a_n^2} + 785\frac{a_{n-8}a_{n-2}}{a_n^2} - 26\frac{a_{n-9}}{a_n}$

Sum of twenty-seven powers of roots  $r_1^{27} + r_2^{27} + \dots + r_n^{27} = \left(\frac{a_{n-1}}{a_n}\right)^{27} - 27\frac{a_{n-1}a_{n-2}}{a_n^2} + 351\frac{a_{n-2}^2}{a_n^2} - 1287\frac{a_{n-3}a_{n-1}}{a_n^2} + 4914\frac{a_{n-4}a_{n-2}}{a_n^2} - 11970\frac{a_{n-5}a_{n-1}}{a_n^2} + 8280\frac{a_{n-6}a_{n-2}}{a_n^2} - 3960\frac{a_{n-7}a_{n-1}}{a_n^2} + 828\frac{a_{n-8}a_{n-2}}{a_n^2} - 27\frac{a_{n-9}}{a_n}$

Sum of twenty-eight powers of roots  $r_1^{28} + r_2^{28} + \dots + r_n^{28} = \left(\frac{a_{n-1}}{a_n}\right)^{28} - 28\frac{a_{n-1}a_{n-2}}{a_n^2} + 378\frac{a_{n-2}^2}{a_n^2} - 1372\frac{a_{n-3}a_{n-1}}{a_n^2} + 5214\frac{a_{n-4}a_{n-2}}{a_n^2} - 12552\frac{a_{n-5}a_{n-1}}{a_n^2} + 8658\frac{a_{n-6}a_{n-2}}{a_n^2} - 4004\frac{a_{n-7}a_{n-1}}{a_n^2} + 865\frac{a_{n-8}a_{n-2}}{a_n^2} - 28\frac{a_{n-9}}{a_n}$

Sum of twenty-nine powers of roots  $r_1^{29} + r_2^{29} + \dots + r_n^{29} = \left(\frac{a_{n-1}}{a_n}\right)^{29} - 29\frac{a_{n-1}a_{n-2}}{a_n^2} + 406\frac{a_{n-2}^2}{a_n^2} - 1463\frac{a_{n-3}a_{n-1}}{a_n^2} + 5581\frac{a_{n-4}a_{n-2}}{a_n^2} - 13203\frac{a_{n-5}a_{n-1}}{a_n^2} + 9180\frac{a_{n-6}a_{n-2}}{a_n^2} - 4284\frac{a_{n-7}a_{n-1}}{a_n^2} + 918\frac{a_{n-8}a_{n-2}}{a_n^2} - 29\frac{a_{n-9}}{a_n}$

Sum of thirty powers of roots  $r_1^{30} + r_2^{30} + \dots + r_n^{30} = \left(\frac{a_{n-1}}{a_n}\right)^{30} - 30\frac{a_{n-1}a_{n-2}}{a_n^2} + 435\frac{a_{n-2}^2}{a_n^2} - 1550\frac{a_{n-3}a_{n-1}}{a_n^2} + 5985\frac{a_{n-4}a_{n-2}}{a_n^2} - 14190\frac{a_{n-5}a_{n-1}}{a_n^2} + 9720\frac{a_{n-6}a_{n-2}}{a_n^2} - 4590\frac{a_{n-7}a_{n-1}}{a_n^2} + 972\frac{a_{n-8}a_{n-2}}{a_n^2} - 30\frac{a_{n-9}}{a_n}$

Sum of thirty-one powers of roots  $r_1^{31} + r_2^{31} + \dots + r_n^{31} = \left(\frac{a_{n-1}}{a_n}\right)^{31} - 31\frac{a_{n-1}a_{n-2}}{a_n^2} + 466\frac{a_{n-2}^2}{a_n^2} - 1641\frac{a_{n-3}a_{n-1}}{a_n^2} + 6351\frac{a_{n-4}a_{n-2}}{a_n^2} - 15183\frac{a_{n-5}a_{n-1}}{a_n^2} + 10080\frac{a_{n-6}a_{n-2}}{a_n^2} - 4782\frac{a_{n-7}a_{n-1}}{a_n^2} + 1008\frac{a_{n-8}a_{n-2}}{a_n^2} - 31\frac{a_{n-9}}{a_n}$

Sum of thirty-two powers of roots  $r_1^{32} + r_2^{32} + \dots + r_n^{32} = \left(\frac{a_{n-1}}{a_n}\right)^{32} - 32\frac{a_{n-1}a_{n-2}}{a_n^2} + 496\frac{a_{n-2}^2}{a_n^2} - 1728\frac{a_{n-3}a_{n-1}}{a_n^2} + 6720\frac{a_{n-4}a_{n-2}}{a_n^2} - 16464\frac{a_{n-5}a_{n-1}}{a_n^2} + 10880\frac{a_{n-6}a_{n-2}}{a_n^2} - 5040\frac{a_{n-7}a_{n-1}}{a_n^2} + 1088\frac{a_{n-8}a_{n-2}}{a_n^2} - 32\frac{a_{n-9}}{a_n}$

Sum of thirty-three powers of roots  $r_1^{33} + r_2^{33} + \dots + r_n^{33} = \left(\frac{a_{n-1}}{a_n}\right)^{33} - 33\frac{a_{n-1}a_{n-2}}{a_n^2} + 527\frac{a_{n-2}^2}{a_n^2} - 1815\frac{a_{n-3}a_{n-1}}{a_n^2} + 7113\frac{a_{n-4}a_{n-2}}{a_n^2} - 17613\frac{a_{n-5}a_{n-1}}{a_n^2} + 116$

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