

## COMPLEX NUMBERS

### DEFINITION

The Imaginary Unit  $i$  is defined as  $i^2 = -1$ .  
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.

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

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

Argument (angle)  $\theta$  is the angle measured from the positive real axis.

Complex Number in Polar Form  $a + bi = r(\cos \theta + i \sin \theta)$

### ALGEBRAIC OPERATIONS

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

Multiplication in Polar Form  $r_1(\cos \theta_1 + i \sin \theta_1) \cdot r_2(\cos \theta_2 + i \sin \theta_2) = r_1 r_2 (\cos(\theta_1 + \theta_2) + i \sin(\theta_1 + \theta_2))$

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 in Polar Form  $\frac{r_1(\cos \theta_1 + i \sin \theta_1)}{r_2(\cos \theta_2 + i \sin \theta_2)} = \frac{r_1}{r_2} (\cos(\theta_1 - \theta_2) + i \sin(\theta_1 - \theta_2))$

Complex Powers of  $i$   $i^0 = 1, i^1 = i, i^2 = -1, i^3 = -i, i^4 = 1$

### EXAMPLES

Example 1: Simplify  $i^5$

$$i^5 = i^4 \cdot i = 1 \cdot i = i$$

$$i^6 = i^4 \cdot i^2 = 1 \cdot (-1) = -1$$

$$i^7 = i^4 \cdot i^3 = 1 \cdot (-i) = -i$$

### ALGEBRA

$$(a + bi)^2 = a^2 + 2abi + (bi)^2 = a^2 + 2abi - b^2$$

$$(a + bi)^3 = a^3 + 3a^2bi + 3a(bi)^2 + (bi)^3 = a^3 + 3a^2bi - 3ab^2 - b^3$$

$$(a + bi)^4 = a^4 + 4a^3bi + 6a^2(bi)^2 + 4a(bi)^3 + (bi)^4 = a^4 + 4a^3bi - 6a^2b^2 - 4ab^3 + b^4$$

$$(a + bi)^5 = a^5 + 5a^4bi + 10a^3(bi)^2 + 10a^2(bi)^3 + 5a(bi)^4 + (bi)^5 = a^5 + 5a^4bi - 10a^3b^2 - 10a^2b^3 + 5ab^4 - b^5$$

$$(a + bi)^6 = a^6 + 6a^5bi + 15a^4(bi)^2 + 20a^3(bi)^3 + 15a^2(bi)^4 + 6a(bi)^5 + (bi)^6 = a^6 + 6a^5bi - 15a^4b^2 - 20a^3b^3 + 15a^2b^4 + 6ab^5 - b^6$$

$$(a + bi)^7 = a^7 + 7a^6bi + 21a^5(bi)^2 + 35a^4(bi)^3 + 35a^3(bi)^4 + 21a^2(bi)^5 + 7a(bi)^6 + (bi)^7 = a^7 + 7a^6bi - 21a^5b^2 - 35a^4b^3 + 35a^3b^4 + 21a^2b^5 + 7ab^6 - b^7$$

$$(a + bi)^8 = a^8 + 8a^7bi + 28a^6(bi)^2 + 56a^5(bi)^3 + 35a^4(bi)^4 + 56a^3(bi)^5 + 28a^2(bi)^6 + 8a(bi)^7 + (bi)^8 = a^8 + 8a^7bi - 28a^6b^2 - 56a^5b^3 + 35a^4b^4 + 56a^3b^5 - 28a^2b^6 - 8ab^7 + b^8$$

### ALGEBRAIC FORM

$$(a + bi)^2 = a^2 + 2abi - b^2$$

$$(a + bi)^3 = a^3 + 3a^2bi - 3ab^2 - b^3$$

$$(a + bi)^4 = a^4 + 4a^3bi - 6a^2b^2 - 4ab^3 + b^4$$

$$(a + bi)^5 = a^5 + 5a^4bi - 10a^3b^2 - 10a^2b^3 + 5ab^4 - b^5$$

$$(a + bi)^6 = a^6 + 6a^5bi - 15a^4b^2 - 20a^3b^3 + 15a^2b^4 + 6ab^5 - b^6$$

$$(a + bi)^7 = a^7 + 7a^6bi - 21a^5b^2 - 35a^4b^3 + 35a^3b^4 + 21a^2b^5 + 7ab^6 - b^7$$

$$(a + bi)^8 = a^8 + 8a^7bi - 28a^6b^2 - 56a^5b^3 + 35a^4b^4 + 56a^3b^5 - 28a^2b^6 - 8ab^7 + b^8$$

## POLYNOMIAL EQUATIONS

### DEFINITION

A polynomial equation of degree  $n$  is an equation of the form  $a_n x^n + a_{n-1} x^{n-1} + \dots + a_1 x + a_0 = 0$  where  $a_n \neq 0$ .

Roots of a polynomial equation are the values of  $x$  that satisfy the equation.

Sum of roots  $-\frac{a_{n-1}}{a_n}$ , Product of roots  $\frac{a_0}{a_n}$

Sum of squares of roots  $\frac{a_{n-1}^2 - 2a_{n-2}a_n}{a_n^2}$

Sum of cubes of roots  $\frac{a_{n-1}^3 - 3a_{n-1}a_{n-2}a_n + 3a_{n-3}a_n^2}{a_n^3}$

Sum of fourth powers of roots  $\frac{a_{n-1}^4 - 4a_{n-1}^2a_{n-2}a_n + 6a_{n-1}a_{n-3}a_n^2 - 3a_{n-2}^2a_n^2}{a_n^4}$

Sum of fifth powers of roots  $\frac{a_{n-1}^5 - 5a_{n-1}^3a_{n-2}a_n + 5a_{n-1}^2a_{n-3}a_n^2 - 5a_{n-1}a_{n-2}^2a_n^2 + 5a_{n-2}a_{n-3}a_n^3}{a_n^5}$

Sum of sixth powers of roots  $\frac{a_{n-1}^6 - 6a_{n-1}^4a_{n-2}a_n + 15a_{n-1}^3a_{n-3}a_n^2 - 12a_{n-1}^2a_{n-2}^2a_n^2 + 6a_{n-1}a_{n-2}a_{n-3}a_n^3 - 6a_{n-2}^2a_{n-3}a_n^3}{a_n^6}$

Sum of seventh powers of roots  $\frac{a_{n-1}^7 - 7a_{n-1}^5a_{n-2}a_n + 21a_{n-1}^4a_{n-3}a_n^2 - 35a_{n-1}^3a_{n-2}^2a_n^2 + 35a_{n-1}^2a_{n-2}a_{n-3}a_n^3 - 21a_{n-1}a_{n-2}^2a_{n-3}a_n^3 + 7a_{n-2}^2a_{n-3}^2a_n^4}{a_n^7}$

Sum of eighth powers of roots  $\frac{a_{n-1}^8 - 8a_{n-1}^6a_{n-2}a_n + 28a_{n-1}^5a_{n-3}a_n^2 - 56a_{n-1}^4a_{n-2}^2a_n^2 + 56a_{n-1}^3a_{n-2}a_{n-3}a_n^3 - 28a_{n-1}^2a_{n-2}^2a_{n-3}a_n^3 + 14a_{n-1}a_{n-2}a_{n-3}^2a_n^4 - 8a_{n-2}^2a_{n-3}^2a_n^4}{a_n^8}$

Sum of ninth powers of roots  $\frac{a_{n-1}^9 - 9a_{n-1}^7a_{n-2}a_n + 36a_{n-1}^6a_{n-3}a_n^2 - 84a_{n-1}^5a_{n-2}^2a_n^2 + 84a_{n-1}^4a_{n-2}a_{n-3}a_n^3 - 36a_{n-1}^3a_{n-2}^2a_{n-3}a_n^3 + 36a_{n-1}^2a_{n-2}a_{n-3}^2a_n^4 - 18a_{n-1}a_{n-2}^2a_{n-3}^2a_n^4 + 9a_{n-2}^2a_{n-3}^3a_n^5}{a_n^9}$

Sum of tenth powers of roots  $\frac{a_{n-1}^{10} - 10a_{n-1}^8a_{n-2}a_n + 45a_{n-1}^7a_{n-3}a_n^2 - 120a_{n-1}^6a_{n-2}^2a_n^2 + 120a_{n-1}^5a_{n-2}a_{n-3}a_n^3 - 60a_{n-1}^4a_{n-2}^2a_{n-3}a_n^3 + 60a_{n-1}^3a_{n-2}a_{n-3}^2a_n^4 - 30a_{n-1}^2a_{n-2}^2a_{n-3}^2a_n^4 + 30a_{n-1}a_{n-2}^2a_{n-3}^3a_n^5 - 10a_{n-2}^2a_{n-3}^3a_n^5}{a_n^{10}}$

Sum of eleventh powers of roots  $\frac{a_{n-1}^{11} - 11a_{n-1}^9a_{n-2}a_n + 55a_{n-1}^8a_{n-3}a_n^2 - 165a_{n-1}^7a_{n-2}^2a_n^2 + 165a_{n-1}^6a_{n-2}a_{n-3}a_n^3 - 77a_{n-1}^5a_{n-2}^2a_{n-3}a_n^3 + 77a_{n-1}^4a_{n-2}a_{n-3}^2a_n^4 - 33a_{n-1}^3a_{n-2}^2a_{n-3}^2a_n^4 + 33a_{n-1}^2a_{n-2}^2a_{n-3}^3a_n^5 - 11a_{n-1}a_{n-2}^2a_{n-3}^3a_n^5 + 11a_{n-2}^2a_{n-3}^3a_n^5}{a_n^{11}}$

Sum of twelfth powers of roots  $\frac{a_{n-1}^{12} - 12a_{n-1}^{10}a_{n-2}a_n + 66a_{n-1}^9a_{n-3}a_n^2 - 220a_{n-1}^8a_{n-2}^2a_n^2 + 220a_{n-1}^7a_{n-2}a_{n-3}a_n^3 - 110a_{n-1}^6a_{n-2}^2a_{n-3}a_n^3 + 110a_{n-1}^5a_{n-2}a_{n-3}^2a_n^4 - 55a_{n-1}^4a_{n-2}^2a_{n-3}^2a_n^4 + 55a_{n-1}^3a_{n-2}^2a_{n-3}^3a_n^5 - 22a_{n-1}^2a_{n-2}^2a_{n-3}^3a_n^5 + 22a_{n-1}a_{n-2}^2a_{n-3}^3a_n^5 - 11a_{n-2}^2a_{n-3}^3a_n^5}{a_n^{12}}$

Sum of thirteenth powers of roots  $\frac{a_{n-1}^{13} - 13a_{n-1}^{11}a_{n-2}a_n + 78a_{n-1}^{10}a_{n-3}a_n^2 - 286a_{n-1}^9a_{n-2}^2a_n^2 + 286a_{n-1}^8a_{n-2}a_{n-3}a_n^3 - 143a_{n-1}^7a_{n-2}^2a_{n-3}a_n^3 + 143a_{n-1}^6a_{n-2}a_{n-3}^2a_n^4 - 71a_{n-1}^5a_{n-2}^2a_{n-3}^2a_n^4 + 71a_{n-1}^4a_{n-2}a_{n-3}^3a_n^5 - 33a_{n-1}^3a_{n-2}^2a_{n-3}^3a_n^5 + 33a_{n-1}^2a_{n-2}^2a_{n-3}^3a_n^5 - 11a_{n-1}a_{n-2}^2a_{n-3}^3a_n^5 + 11a_{n-2}^2a_{n-3}^3a_n^5}{a_n^{13}}$

Sum of fourteenth powers of roots  $\frac{a_{n-1}^{14} - 14a_{n-1}^{12}a_{n-2}a_n + 91a_{n-1}^{11}a_{n-3}a_n^2 - 364a_{n-1}^{10}a_{n-2}^2a_n^2 + 364a_{n-1}^9a_{n-2}a_{n-3}a_n^3 - 182a_{n-1}^8a_{n-2}^2a_{n-3}a_n^3 + 182a_{n-1}^7a_{n-2}a_{n-3}^2a_n^4 - 91a_{n-1}^6a_{n-2}^2a_{n-3}^2a_n^4 + 91a_{n-1}^5a_{n-2}a_{n-3}^3a_n^5 - 42a_{n-1}^4a_{n-2}^2a_{n-3}^3a_n^5 + 42a_{n-1}^3a_{n-2}^2a_{n-3}^3a_n^5 - 14a_{n-1}^2a_{n-2}^2a_{n-3}^3a_n^5 + 14a_{n-1}a_{n-2}^2a_{n-3}^3a_n^5 - 7a_{n-2}^2a_{n-3}^3a_n^5}{a_n^{14}}$

Sum of fifteenth powers of roots  $\frac{a_{n-1}^{15} - 15a_{n-1}^{13}a_{n-2}a_n + 105a_{n-1}^{12}a_{n-3}a_n^2 - 420a_{n-1}^{11}a_{n-2}^2a_n^2 + 420a_{n-1}^{10}a_{n-2}a_{n-3}a_n^3 - 210a_{n-1}^9a_{n-2}^2a_{n-3}a_n^3 + 210a_{n-1}^8a_{n-2}a_{n-3}^2a_n^4 - 105a_{n-1}^7a_{n-2}^2a_{n-3}^2a_n^4 + 105a_{n-1}^6a_{n-2}a_{n-3}^3a_n^5 - 42a_{n-1}^5a_{n-2}^2a_{n-3}^3a_n^5 + 42a_{n-1}^4a_{n-2}^2a_{n-3}^3a_n^5 - 14a_{n-1}^3a_{n-2}^2a_{n-3}^3a_n^5 + 14a_{n-1}^2a_{n-2}^2a_{n-3}^3a_n^5 - 7a_{n-1}a_{n-2}^2a_{n-3}^3a_n^5 + 7a_{n-2}^2a_{n-3}^3a_n^5}{a_n^{15}}$

Sum of sixteenth powers of roots  $\frac{a_{n-1}^{16} - 16a_{n-1}^{14}a_{n-2}a_n + 120a_{n-1}^{13}a_{n-3}a_n^2 - 560a_{n-1}^{12}a_{n-2}^2a_n^2 + 560a_{n-1}^{11}a_{n-2}a_{n-3}a_n^3 - 280a_{n-1}^{10}a_{n-2}^2a_{n-3}a_n^3 + 280a_{n-1}^9a_{n-2}a_{n-3}^2a_n^4 - 140a_{n-1}^8a_{n-2}^2a_{n-3}^2a_n^4 + 140a_{n-1}^7a_{n-2}a_{n-3}^3a_n^5 - 56a_{n-1}^6a_{n-2}^2a_{n-3}^3a_n^5 + 56a_{n-1}^5a_{n-2}^2a_{n-3}^3a_n^5 - 16a_{n-1}^4a_{n-2}^2a_{n-3}^3a_n^5 + 16a_{n-1}^3a_{n-2}^2a_{n-3}^3a_n^5 - 8a_{n-1}^2a_{n-2}^2a_{n-3}^3a_n^5 + 8a_{n-1}a_{n-2}^2a_{n-3}^3a_n^5 - 4a_{n-2}^2a_{n-3}^3a_n^5}{a_n^{16}}$

Sum of seventeenth powers of roots  $\frac{a_{n-1}^{17} - 17a_{n-1}^{15}a_{n-2}a_n + 136a_{n-1}^{14}a_{n-3}a_n^2 - 680a_{n-1}^{13}a_{n-2}^2a_n^2 + 680a_{n-1}^{12}a_{n-2}a_{n-3}a_n^3 - 340a_{n-1}^{11}a_{n-2}^2a_{n-3}a_n^3 + 340a_{n-1}^{10}a_{n-2}a_{n-3}^2a_n^4 - 170a_{n-1}^9a_{n-2}^2a_{n-3}^2a_n^4 + 170a_{n-1}^8a_{n-2}a_{n-3}^3a_n^5 - 85a_{n-1}^7a_{n-2}^2a_{n-3}^3a_n^5 + 85a_{n-1}^6a_{n-2}^2a_{n-3}^3a_n^5 - 17a_{n-1}^5a_{n-2}^2a_{n-3}^3a_n^5 + 17a_{n-1}^4a_{n-2}^2a_{n-3}^3a_n^5 - 8a_{n-1}^3a_{n-2}^2a_{n-3}^3a_n^5 + 8a_{n-1}^2a_{n-2}^2a_{n-3}^3a_n^5 - 4a_{n-1}a_{n-2}^2a_{n-3}^3a_n^5 + 4a_{n-2}^2a_{n-3}^3a_n^5}{a_n^{17}}$

Sum of eighteenth powers of roots  $\frac{a_{n-1}^{18} - 18a_{n-1}^{16}a_{n-2}a_n + 153a_{n-1}^{15}a_{n-3}a_n^2 - 816a_{n-1}^{14}a_{n-2}^2a_n^2 + 816a_{n-1}^{13}a_{n-2}a_{n-3}a_n^3 - 408a_{n-1}^{12}a_{n-2}^2a_{n-3}a_n^3 + 408a_{n-1}^{11}a_{n-2}a_{n-3}^2a_n^4 - 204a_{n-1}^{10}a_{n-2}^2a_{n-3}^2a_n^4 + 204a_{n-1}^9a_{n-2}a_{n-3}^3a_n^5 - 102a_{n-1}^8a_{n-2}^2a_{n-3}^3a_n^5 + 102a_{n-1}^7a_{n-2}^2a_{n-3}^3a_n^5 - 18a_{n-1}^6a_{n-2}^2a_{n-3}^3a_n^5 + 18a_{n-1}^5a_{n-2}^2a_{n-3}^3a_n^5 - 9a_{n-1}^4a_{n-2}^2a_{n-3}^3a_n^5 + 9a_{n-1}^3a_{n-2}^2a_{n-3}^3a_n^5 - 4a_{n-1}^2a_{n-2}^2a_{n-3}^3a_n^5 + 4a_{n-1}a_{n-2}^2a_{n-3}^3a_n^5 - 2a_{n-2}^2a_{n-3}^3a_n^5}{a_n^{18}}$

Sum of nineteenth powers of roots  $\frac{a_{n-1}^{19} - 19a_{n-1}^{17}a_{n-2}a_n + 171a_{n-1}^{16}a_{n-3}a_n^2 - 903a_{n-1}^{15}a_{n-2}^2a_n^2 + 903a_{n-1}^{14}a_{n-2}a_{n-3}a_n^3 - 451a_{n-1}^{13}a_{n-2}^2a_{n-3}a_n^3 + 451a_{n-1}^{12}a_{n-2}a_{n-3}^2a_n^4 - 225a_{n-1}^{11}a_{n-2}^2a_{n-3}^2a_n^4 + 225a_{n-1}^{10}a_{n-2}a_{n-3}^3a_n^5 - 112a_{n-1}^9a_{n-2}^2a_{n-3}^3a_n^5 + 112a_{n-1}^8a_{n-2}^2a_{n-3}^3a_n^5 - 19a_{n-1}^7a_{n-2}^2a_{n-3}^3a_n^5 + 19a_{n-1}^6a_{n-2}^2a_{n-3}^3a_n^5 - 9a_{n-1}^5a_{n-2}^2a_{n-3}^3a_n^5 + 9a_{n-1}^4a_{n-2}^2a_{n-3}^3a_n^5 - 4a_{n-1}^3a_{n-2}^2a_{n-3}^3a_n^5 + 4a_{n-1}^2a_{n-2}^2a_{n-3}^3a_n^5 - 2a_{n-1}a_{n-2}^2a_{n-3}^3a_n^5 + 2a_{n-2}^2a_{n-3}^3a_n^5}{a_n^{19}}$

Sum of twentieth powers of roots  $\frac{a_{n-1}^{20} - 20a_{n-1}^{18}a_{n-2}a_n + 190a_{n-1}^{17}a_{n-3}a_n^2 - 960a_{n-1}^{16}a_{n-2}^2a_n^2 + 960a_{n-1}^{15}a_{n-2}a_{n-3}a_n^3 - 480a_{n-1}^{14}a_{n-2}^2a_{n-3}a_n^3 + 480a_{n-1}^{13}a_{n-2}a_{n-3}^2a_n^4 - 240a_{n-1}^{12}a_{n-2}^2a_{n-3}^2a_n^4 + 240a_{n-1}^{11}a_{n-2}a_{n-3}^3a_n^5 - 120a_{n-1}^{10}a_{n-2}^2a_{n-3}^3a_n^5 + 120a_{n-1}^9a_{n-2}^2a_{n-3}^3a_n^5 - 20a_{n-1}^8a_{n-2}^2a_{n-3}^3a_n^5 + 20a_{n-1}^7a_{n-2}^2a_{n-3}^3a_n^5 - 10a_{n-1}^6a_{n-2}^2a_{n-3}^3a_n^5 + 10a_{n-1}^5a_{n-2}^2a_{n-3}^3a_n^5 - 5a_{n-1}^4a_{n-2}^2a_{n-3}^3a_n^5 + 5a_{n-1}^3a_{n-2}^2a_{n-3}^3a_n^5 - 2a_{n-1}^2a_{n-2}^2a_{n-3}^3a_n^5 + 2a_{n-1}a_{n-2}^2a_{n-3}^3a_n^5 - a_{n-2}^2a_{n-3}^3a_n^5}{a_n^{20}}$

Sum of twenty-first powers of roots  $\frac{a_{n-1}^{21} - 21a_{n-1}^{19}a_{n-2}a_n + 203a_{n-1}^{18}a_{n-3}a_n^2 - 1008a_{n-1}^{17}a_{n-2}^2a_n^2 + 1008a_{n-1}^{16}a_{n-2}a_{n-3}a_n^3 - 504a_{n-1}^{15}a_{n-2}^2a_{n-3}a_n^3 + 504a_{n-1}^{14}a_{n-2}a_{n-3}^2a_n^4 - 252a_{n-1}^{13}a_{n-2}^2a_{n-3}^2a_n^4 + 252a_{n-1}^{12}a_{n-2}a_{n-3}^3a_n^5 - 126a_{n-1}^{11}a_{n-2}^2a_{n-3}^3a_n^5 + 126a_{n-1}^{10}a_{n-2}^2a_{n-3}^3a_n^5 - 21a_{n-1}^9a_{n-2}^2a_{n-3}^3a_n^5 + 21a_{n-1}^8a_{n-2}^2a_{n-3}^3a_n^5 - 10a_{n-1}^7a_{n-2}^2a_{n-3}^3a_n^5 + 10a_{n-1}^6a_{n-2}^2a_{n-3}^3a_n^5 - 5a_{n-1}^5a_{n-2}^2a_{n-3}^3a_n^5 + 5a_{n-1}^4a_{n-2}^2a_{n-3}^3a_n^5 - 2a_{n-1}^3a_{n-2}^2a_{n-3}^3a_n^5 + 2a_{n-1}^2a_{n-2}^2a_{n-3}^3a_n^5 - a_{n-1}a_{n-2}^2a_{n-3}^3a_n^5 + a_{n-2}^2a_{n-3}^3a_n^5}{a_n^{21}}$

Sum of twenty-second powers of roots  $\frac{a_{n-1}^{22} - 22a_{n-1}^{20}a_{n-2}a_n + 220a_{n-1}^{19}a_{n-3}a_n^2 - 1122a_{n-1}^{18}a_{n-2}^2a_n^2 + 1122a_{n-1}^{17}a_{n-2}a_{n-3}a_n^3 - 561a_{n-1}^{16}a_{n-2}^2a_{n-3}a_n^3 + 561a_{n-1}^{15}a_{n-2}a_{n-3}^2a_n^4 - 280a_{n-1}^{14}a_{n-2}^2a_{n-3}^2a_n^4 + 280a_{n-1}^{13}a_{n-2}a_{n-3}^3a_n^5 - 140a_{n-1}^{12}a_{n-2}^2a_{n-3}^3a_n^5 + 140a_{n-1}^{11}a_{n-2}^2a_{n-3}^3a_n^5 - 22a_{n-1}^{10}a_{n-2}^2a_{n-3}^3a_n^5 + 22a_{n-1}^9a_{n-2}^2a_{n-3}^3a_n^5 - 11a_{n-1}^8a_{n-2}^2a_{n-3}^3a_n^5 + 11a_{n-1}^7a_{n-2}^2a_{n-3}^3a_n^5 - 5a_{n-1}^6a_{n-2}^2a_{n-3}^3a_n^5 + 5a_{n-1}^5a_{n-2}^2a_{n-3}^3a_n^5 - 2a_{n-1}^4a_{n-2}^2a_{n-3}^3a_n^5 + 2a_{n-1}^3a_{n-2}^2a_{n-3}^3a_n^5 - a_{n-1}^2a_{n-2}^2a_{n-3}^3a_n^5 + a_{n-1}a_{n-2}^2a_{n-3}^3a_n^5 - a_{n-2}^2a_{n-3}^3a_n^5}{a_n^{22}}$

Sum of twenty-third powers of roots  $\frac{a_{n-1}^{23} - 23a_{n-1}^{21}a_{n-2}a_n + 231a_{n-1}^{20}a_{n-3}a_n^2 - 1163a_{n-1}^{19}a_{n-2}^2a_n^2 + 1163a_{n-1}^{18}a_{n-2}a_{n-3}a_n^3 - 581a_{n-1}^{17}a_{n-2}^2a_{n-3}a_n^3 + 581a_{n-1}^{16}a_{n-2}a_{n-3}^2a_n^4 - 290a_{n-1}^{15}a_{n-2}^2a_{n-3}^2a_n^4 + 290a_{n-1}^{14}a_{n-2}a_{n-3}^3a_n^5 - 145a_{n-1}^{13}a_{n-2}^2a_{n-3}^3a_n^5 + 145a_{n-1}^{12}a_{n-2}^2a_{n-3}^3a_n^5 - 23a_{n-1}^{11}a_{n-2}^2a_{n-3}^3a_n^5 + 23a_{n-1}^{10}a_{n-2}^2a_{n-3}^3a_n^5 - 11a_{n-1}^9a_{n-2}^2a_{n-3}^3a_n^5 + 11a_{n-1}^8a_{n-2}^2a_{n-3}^3a_n^5 - 5a_{n-1}^7a_{n-2}^2a_{n-3}^3a_n^5 + 5a_{n-1}^6a_{n-2}^2a_{n-3}^3a_n^5 - 2a_{n-1}^5a_{n-2}^2a_{n-3}^3a_n^5 + 2a_{n-1}^4a_{n-2}^2a_{n-3}^3a_n^5 - a_{n-1}^3a_{n-2}^2a_{n-3}^3a_n^5 + a_{n-1}^2a_{n-2}^2a_{n-3}^3a_n^5 - a_{n-1}a_{n-2}^2a_{n-3}^3a_n^5 + a_{n-2}^2a_{n-3}^3a_n^5}{a_n^{23}}$

Sum of twenty-four powers of roots  $\frac{a_{n-1}^{24} - 24a_{n-1}^{22}a_{n-2}a_n + 242a_{n-1}^{21}a_{n-3}a_n^2 - 1232a_{n-1}^{20}a_{n-2}^2a_n^2 + 1232a_{n-1}^{19}a_{n-2}a_{n-3}a_n^3 - 616a_{n-1}^{18}a_{n-2}^2a_{n-3}a_n^3 + 616a_{n-1}^{17}a_{n-2}a_{n-3}^2a$

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