

Notes

101.01 Fermat's last theorem for $n = 3$ revisited

In the 17th century, Fermat discovered the unsolvability in non-zero integers of the equation $x^3 + y^3 = z^3$ (but his proof has been lost). In 1770, Euler gave a proof (see [1, pp. 39-42]), followed by Gauss (see [1, pp. 42-45]) and Legendre (see [2, pp. 357-360]). Various proofs were obtained by Lamé, Tait, Günther, Gambioli, Krey, Thue, Carmichael and by many other mathematicians. A proof in Euler's style is based on a crucial lemma, followed by an infinite descent that is divided in *two* main cases (according as to whether the g.c.d. of $x + y$ and $x^2 - xy + y^2$ is 1 or 3). In the present version, the crucial lemma receives a short proof and an additional observation allows elimination of one of the two main cases.

General properties of the ring of units of a quadratic field (needed here) can be found in [3].

Notations: $\mathbb{Z}^*$ stands for $\mathbb{Z} - \{0\}$ and $\mathbb{N}^*$ for $\mathbb{N} - \{0\}$. Throughout, a, b lie in $\mathbb{Z}^*$ and (a, b) denotes the g.c.d. of a and b .

Introduction

Recall that every prime $p = 6k + 1$ of $\mathbb{N}$ has a unique representation as $p = r^2 + 3s^2$, $r, s \in \mathbb{N}^*$. Set $\omega = \frac{-1 + \sqrt{-3}}{2}$,

$$A = \mathbb{Z}(\omega) = \left\{ \frac{m + n\sqrt{-3}}{2}, m, n \in \mathbb{Z}, m + n \text{ even} \right\} \supset \mathbb{Z}(\sqrt{-3}).$$

The units of A are $\pm 1, \pm \omega, \pm \omega^2$. A is a euclidean (hence factorial) ring for the norm $N(\alpha + \beta\sqrt{-3}) = \alpha^2 + 3\beta^2$. Define the *atoms* of A , *all lying in $\mathbb{Z}(\sqrt{-3})$* , as the elements: 2, $p = 6k - 1$ prime of $\mathbb{N}$, $\sqrt{-3}$, $r + s\sqrt{-3}$ and $r - s\sqrt{-3}$ for each prime $p = 6k + 1$ of $\mathbb{N}$, $p = r^2 + 3s^2$, $r, s \in \mathbb{N}^*$. The atoms of A , pairwise coprime, represent (up to units) *all* the irreducible (or prime) elements of A . For example, the six prime elements $\pm 5, \pm 5\omega, \pm 5\omega^2$ are all represented by the single atom 5. Let $z \in A - \{0\}$; z not a unit. Then z has a unique *atomic* decomposition as $z = \varepsilon \times \pi$, where ε is a unit of A and $\pi \in \mathbb{Z}(\sqrt{-3})$ is a product of atoms in a *unique* way (up to order). For example, $70\left(\frac{3 + \sqrt{-3}}{2}\right) = (-\omega) \times 2 \times 5 \times \sqrt{-3} \times (2 + \sqrt{-3}) \times (2 - \sqrt{-3})$. Every atom of z corresponds to *one* prime factor (or its square) of $N(z)$: 2 to 2^2 , $p = 6 - 1$ to p^2 , $\sqrt{-3}$ to 3, $r + s\sqrt{-3}$, respectively $r - s\sqrt{-3}$, to $p (= 6k + 1) = r^2 + 3s^2$.

The following properties are trivial:

- (R1) If $a + b$ is odd, then the atom 2 does not divide $a + b\sqrt{-3}$ in A .
- (R2) If $(a, b) = 1$, then the atom $p = 6k - 1$ does not divide $a + b\sqrt{-3}$ in A .
- (R3) If $(a, b) = 1$, then the square of the atom $\sqrt{-3}$ does not divide $a + b\sqrt{-3}$ in A .

Notes On Fermats Last Theorem

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