

Introduction

Our starting point is the following famous result of Lagrange.

Lagrange. Every positive integer can be written as the sum of four squares. (Note that we include 0 as a square.)

This is potentially a surprising result, but once one believes it one might naturally ask whether something similar holds for cubes, and so on. In 1770, Waring asserted (in Latin) that every positive integer is a sum of 4 squares, or 9 cubes, or 19 biquadrates, and so on.

$\uparrow$ $\uparrow$
 fourth powers 777

This gave rise to Waring's problem, which is to prove the following.

Conjecture (Waring's Problem). For each $k \geq 2$, there exists $s = s(k)$ such that every positive integer can be written as a sum of s k^{th} powers.

This was first proved by Hilbert in 1909. In the 1920s, Hardy and Littlewood gave a new proof using what is now known as the Hardy-Littlewood circle method. Their proof gave an asymptotic formula for the number of ways to write a large N as a sum of s k^{th} powers.

Since then, there has been a lot of work on applying the circle method to other problems. One notable example is Vinogradov's proof that every sufficiently large odd integer is a sum of three primes. His slight variant on the circle method is the basis of our approach in this course.

The first key idea is to count the solutions in order to deduce the existence of at least one. We are interested in

$$\left| \left\{ (x_1, \dots, x_s) \in \mathbb{N}^s : N = x_1^k + \dots + x_s^k \right\} \right|.$$

We are interested in the smallest possible s ; this is still a topic of research. In fact, there are two relevant quantities.

Definition. Let $g(k)$ be the smallest s such that every positive integer is a sum of s k^{th} powers. Let $G(k)$ be the smallest s such that every *sufficiently large* positive integer is a sum of s k^{th} powers.

The value of $g(k)$ is almost known for all k , but this is for boring reasons. For example, $3^k - 1$ is difficult to write as a sum of k^{th} powers because the only available summands are 1 and 2^k . This forces $g(k)$ to be artificially large (at least for some k).

The value of $G(k)$ is more interesting and much less well understood. We know that $G(2) = 4$ and that $G(4) = 16$, and otherwise we have upper and lower bounds that do not meet.

Our aim here is to obtain an upper bound for $G(k)$, but it will not be very good.

We will count solutions using an integral. We have

$$\left| \left\{ (x_1, \dots, x_s) \in \mathbb{N}^s : N = x_1^k + \dots + x_s^k \right\} \right| = \int_0^1 \left(\sum_{n=0}^{N^{1/k}} e^{2\pi i n^k} \right)^s e^{-2\pi i \theta N} d\theta.$$

Researches On Warings Problem

Wenbin Ji



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