

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.

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 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

Léo Pomar



Researches On Waring's Problem:

Researches on Waring's Problem Leonard Eugene Dickson, 1935 Research Schools on Number Theory in India Purabi Mukherji, 2021-01-05 This book is an attempt to describe the gradual development of the major schools of research on number theory in South India Punjab Mumbai Bengal and Bihar including the establishment of Tata Institute of Fundamental Research TIFR Mumbai a landmark event in the history of research of number theory in India Research on number theory in India during modern times started with the advent of the iconic genius Srinivasa Ramanujan inspiring mathematicians around the world This book discusses the national and international impact of the research made by Indian number theorists It also includes a carefully compiled comprehensive bibliography of major 20th century Indian number theorists making this book important from the standpoint of historic documentation and a valuable resource for researchers of the field for their literature survey This book also briefly discusses the importance of number theory in the modern world of mathematics including applications of the results developed by indigenous number theorists in practical fields Since the book is written from the viewpoint of the history of science technical jargon and mathematical expressions have been avoided as much as possible Researches on Waring's Problem Leonard Eugene Dickson, 2013-07 **Waring's Problem in Number Fields** Morley A. Davidson, 1995 *Research Problems in Function Theory* Walter K. Hayman, Eleanor F. Lingham, 2019-09-07 In 1967 Walter K Hayman published *Research Problems in Function Theory* a list of 141 problems in seven areas of function theory In the decades following this list was extended to include two additional areas of complex analysis updates on progress in solving existing problems and over 520 research problems from mathematicians worldwide It became known as Hayman's List This Fiftieth Anniversary Edition contains the complete Hayman's List for the first time in book form along with 31 new problems by leading international mathematicians This list has directed complex analysis research for the last half century and the new edition will help guide future research in the subject The book contains up to date information on each problem gathered from the international mathematics community and where possible suggests directions for further investigation Aimed at both early career and established researchers this book provides the key problems and results needed to progress in the most important research questions in complex analysis and documents the developments of the past 50 years *Unsolved Problems in Number Theory* Richard Guy, R.K. Guy, 2013-06-29 To many laymen mathematicians appear to be problem solvers people who do hard sums Even inside the profession we classify ourselves as either theorists or problem solvers Mathematics is kept alive much more than by the activities of either class by the appearance of a succession of unsolved problems both from within mathematics itself and from the increasing number of disciplines where it is applied Mathematics often owes more to those who ask questions than to those who answer them The solution of a problem may stifle interest in the area around it But Fermat's Last Theorem because it is not yet a theorem has generated a great deal of good mathematics whether goodness is judged by beauty by depth or by applicability To pose good unsolved problems is a

difficult art The balance between triviality and hopeless unsolvability is delicate There are many simply stated problems which experts tell us are unlikely to be solved in the next generation But we have seen the Four Color Conjecture settled even if we don't live long enough to learn the status of the Riemann and Goldbach hypotheses of twin primes or Mersenne primes or of odd perfect numbers On the other hand unsolved problems may not be unsolved at all or may be much more tractable than was at first thought

Research on Waring's Problem Leonard Eugene Dickson, 1935

Sieve Methods, Exponential Sums, and Their Applications in Number Theory G. R. H. Greaves, G. Harman, M. N. Huxley, 1997-01-30

State of the art analytic number theory proceedings Analytic Methods for Diophantine Equations and Diophantine Inequalities H. Davenport, 2005-02-07 Harold Davenport was one of the truly great mathematicians of the twentieth century Based on lectures he gave at the University of Michigan in the early 1960s this book is concerned with the use of analytic methods in the study of integer solutions to Diophantine equations and Diophantine inequalities It provides an excellent introduction to a timeless area of number theory that is still as widely researched today as it was when the book originally appeared The three main themes of the book are Waring's problem and the representation of integers by diagonal forms the solubility in integers of systems of forms in many variables and the solubility in integers of diagonal inequalities For the second edition of the book a comprehensive foreword has been added in which three prominent authorities describe the modern context and recent developments A thorough bibliography has also been added

Proceedings of the London Mathematical Society London Mathematical Society, 1928 Papers presented to J E Littlewood on his 80th birthday issued as 3d ser v 14 A 1965

An Introduction to Scientific Research Edgar Bright Wilson, 1990-01-01 Noted scientist's exceptionally clear pragmatic guide to principles and procedures useful in a wide range of sciences Design of experiments and apparatus classification sampling and measurement analysis of experimental data errors of measurement probability randomness and logic much more Indispensable for any researcher 1952 edition 49 illustrations

Issues in Algebra, Geometry, and Topology: 2013 Edition, 2013-05-01 Issues in Algebra Geometry and Topology 2013 Edition is a ScholarlyEditions book that delivers timely authoritative and comprehensive information about Topology The editors have built Issues in Algebra Geometry and Topology 2013 Edition on the vast information databases of ScholarlyNews You can expect the information about Topology in this book to be deeper than what you can access anywhere else as well as consistently reliable authoritative informed and relevant The content of Issues in Algebra Geometry and Topology 2013 Edition has been produced by the world's leading scientists engineers analysts research institutions and companies All of the content is from peer reviewed sources and all of it is written assembled and edited by the editors at ScholarlyEditions and available exclusively from us You now have a source you can cite with authority confidence and credibility More information is available at <http://www.ScholarlyEditions.com>

Research Advances in Alcohol and Drug Problems Reginald Smart, 2013-11-22 This book continues the series of reviews of research advances first published in 1974 The editors aim

here is to present critical and integrative reviews by internationally recognized scholars of areas in which there has been much recent research In this task we have been greatly helped by the staff of Plenum Press and the Advisory Panel listed at the front of this volume Several members of the Panel have retired Dr W M D Paton Dr K Bruun Dr K F Killam and Dr J R Seeley Dr Klaus Makela has accepted our invitation to join the Panel Unfortunately one member of the Panel Professor William McGlothlin died as a result of a tragic accident He was a gifted and sensitive researcher His work over many years was well known to those studying alcohol and drug problems We want to acknowledge his contributions to the Research Advances Series and to the field in general The editors wish to acknowledge the help of Julliana Newell Ayoub in preparation of this volume This volume contains three papers by H Fingarette R Room and B Kissin on The Disease Concept They were originally prepared for an earlier volume but could not be included because of scheduling problems The editors and not the authors are responsible for this delay Because they are primarily philosophical and theoretical in nature they are not diminished in value by the lesser number of references to recent research

CRC Concise Encyclopedia of Mathematics Eric W. Weisstein, 2002-12-12 Upon publication the first edition of the CRC Concise Encyclopedia of Mathematics received overwhelming accolades for its unparalleled scope readability and utility It soon took its place among the top selling books in the history of Chapman Hall CRC and its popularity continues unabated Yet also unabated has been the *Revue Semestrielle Des Publications Mathématiques*, 1926

Open Problems in Mathematics John Forbes Nash, Jr., Michael Th. Rassias, 2016-07-05 The goal in putting together this unique compilation was to present the current status of the solutions to some of the most essential open problems in pure and applied mathematics Emphasis is also given to problems in interdisciplinary research for which mathematics plays a key role This volume comprises highly selected contributions by some of the most eminent mathematicians in the international mathematical community on longstanding problems in very active domains of mathematical research A joint preface by the two volume editors is followed by a personal farewell to John F Nash Jr written by Michael Th Rassias An introduction by Mikhail Gromov highlights some of Nash's legendary mathematical achievements The treatment in this book includes open problems in the following fields algebraic geometry number theory analysis discrete mathematics PDEs differential geometry topology K theory game theory fluid mechanics dynamical systems and ergodic theory cryptography theoretical computer science and more Extensive discussions surrounding the progress made for each problem are designed to reach a wide community of readers from graduate students and established research mathematicians to physicists computer scientists economists and research scientists who are looking to develop essential and modern new methods and theories to solve a variety of open problems

Collected Papers of Srinivasa Ramanujan Srinivasa Ramanujan Aiyangar, 1927

The Hardy-Littlewood Method , First Course in the Theory of Equations Leonard Eugene Dickson, 1922 The theory of equations is not only a necessity in the subsequent mathematical courses and their applications it furnishes an illuminating sequel to geometry algebra and analytic geometry It

was to meet the needs of the student in regard to earlier and future mathematical courses that this book was planned It is addressed to younger students and may be used parallel with a course in differential calculus Simpler and more detailed proofs are employed and exercises are simpler more numerous of greater variety and involve more practical applications

Journal of the London Mathematical Society London Mathematical Society, 1928

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Table of Contents Researches On Warings Problem

1. Understanding the eBook Researches On Warings Problem
 - The Rise of Digital Reading Researches On Warings Problem
 - Advantages of eBooks Over Traditional Books
2. Identifying Researches On Warings Problem
 - Exploring Different Genres
 - Considering Fiction vs. Non-Fiction
 - Determining Your Reading Goals
3. Choosing the Right eBook Platform
 - Popular eBook Platforms
 - Features to Look for in an Researches On Warings Problem
 - User-Friendly Interface
4. Exploring eBook Recommendations from Researches On Warings Problem
 - Personalized Recommendations
 - Researches On Warings Problem User Reviews and Ratings
 - Researches On Warings Problem and Bestseller Lists
5. Accessing Researches On Warings Problem Free and Paid eBooks

- Researches On Warings Problem Public Domain eBooks
- Researches On Warings Problem eBook Subscription Services
- Researches On Warings Problem Budget-Friendly Options
- 6. Navigating Researches On Warings Problem eBook Formats
 - ePub, PDF, MOBI, and More
 - Researches On Warings Problem Compatibility with Devices
 - Researches On Warings Problem Enhanced eBook Features
- 7. Enhancing Your Reading Experience
 - Adjustable Fonts and Text Sizes of Researches On Warings Problem
 - Highlighting and Note-Taking Researches On Warings Problem
 - Interactive Elements Researches On Warings Problem
- 8. Staying Engaged with Researches On Warings Problem
 - Joining Online Reading Communities
 - Participating in Virtual Book Clubs
 - Following Authors and Publishers Researches On Warings Problem
- 9. Balancing eBooks and Physical Books Researches On Warings Problem
 - Benefits of a Digital Library
 - Creating a Diverse Reading Collection Researches On Warings Problem
- 10. Overcoming Reading Challenges
 - Dealing with Digital Eye Strain
 - Minimizing Distractions
 - Managing Screen Time
- 11. Cultivating a Reading Routine Researches On Warings Problem
 - Setting Reading Goals Researches On Warings Problem
 - Carving Out Dedicated Reading Time
- 12. Sourcing Reliable Information of Researches On Warings Problem
 - Fact-Checking eBook Content of Researches On Warings Problem
 - Distinguishing Credible Sources
- 13. Promoting Lifelong Learning
 - Utilizing eBooks for Skill Development

- Exploring Educational eBooks

14. Embracing eBook Trends

- Integration of Multimedia Elements
- Interactive and Gamified eBooks

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