

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

Eric W. Weisstein



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 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 **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 **Research on Waring's Problem** Leonard Eugene Dickson, 1935 The Hardy-Littlewood Method, **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 d **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 **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 *Springer-Verlag: History of a Scientific Publishing House* Heinz Sarkowski, Heinz

Götze,1996-10-07 A chronicle written only by someone for whom the present important Goethe Maximen und Reflexionen The second volume of our company s history differs from the first in several ways With a great appreciation of history Heinz Sarkowski has impressively reconstructed the company cor spondence which is fortunately almost completely preserved and made it speak There is an inexhaustible amount of c rrespondence pertaining to the period I have taken it upon myself to cover and working through it properly not only would have required many years but also would have detracted from the immediacy of the account Thus I decided to proceed from personal experience to describe what has happened and to provide details gleaned from the correspondence I have counted here by no means only my own but rather the personal experiences of the many company members and employees who are mentioned below With the founding of the New York firm developments branch out becoming parallel but separate and the change from one scene to another repeatedly interrupts the continuing course of events and the chronological flow of the report In this connection the occasional repetition of certain facts was avoidable In some places however it seemed more appropriate not to interrupt particular lines of development but to describe them in continuity without regard to specific periods of time *Springer-Verlag: History of a Scientific Publishing House*

Heinz Götze,2008-12-10 A chronicle written only by someone for whom the present important Goethe Maximen und Reflexionen The second volume of our company s history differs from the first in several ways With a great appreciation of history Heinz Sarkowski has impressively reconstructed the company cor spondence which is fortunately almost completely preserved and made it speak There is an inexhaustible amount of c rrespondence pertaining to the period I have taken it upon myself to cover and working through it properly not only would have required many years but also would have detracted from the immediacy of the account Thus I decided to proceed from personal experience to describe what has happened and to provide details gleaned from the correspondence I have counted here by no means only my own but rather the personal experiences of the many company members and employees who are mentioned below With the founding of the New York firm developments branch out becoming parallel but separate and the change from one scene to another repeatedly interrupts the continuing course of events and the chronological flow of the report In this connection the occasional repetition of certain facts was avoidable In some places however it seemed more appropriate not to interrupt particular lines of development but to describe them in continuity without regard to specific periods of time

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