

Hard Mathematical Olympiad Problems Their Solutions

Now in its third decade, the Colorado Mathematical Olympiad (CMO), founded by the author, has become an annual state-wide competition, hosting many hundreds of middle and high school contestants each year. This book presents a year-by-year history of the CMO from 2004–2013 with all the problems from the competitions and their solutions. Additionally, the book includes 10 further explorations, bridges from solved Olympiad problems to ‘real’ mathematics, bringing young readers to the forefront of various fields of mathematics. This book contains more than just problems, solutions, and event statistics — it tells a compelling story involving the lives of those who have been part of the Olympiad, their reminiscences of the past and successes of the present. I am almost speechless facing the ingenuity and inventiveness demonstrated in the problems proposed in the third decade of these Olympics. However, equally impressive is the drive and persistence of the originator and living soul of them. It is hard for me to imagine the enthusiasm and commitment needed to work singlehandedly on such an endeavor over several decades. —Branko Grünbaum, University of Washington

After decades of hunting for Olympiad problems, and struggling to create Olympiad problems, he has become an extraordinary connoisseur and creator of Olympiad problems. The Olympiad problems were very good, from the beginning, but in the third decade the problems have become extraordinarily good. Every brace of 5 problems is a work of art. The harder individual problems range in quality from brilliant to work-of-genius... The same goes for the “Further Explorations” part of the book. Great mathematics and mathematical questions are immersed in a sauce of fascinating anecdote and reminiscence. If you could have only one book to enjoy while stranded on a desert island, this would be a good choice. Like Gauss, Alexander Soifer would not hesitate to inject Eureka! at the right moment. Like van der Waerden, he can transform a dispassionate exercise in logic into a compelling account of sudden insights and ultimate triumph. — Cecil Rousseau Chair, USA Mathematical Olympiad Committee

A delightful feature of the book is that in the second part more related problems are discussed. Some of them are still unsolved. —Paul Erdős

The book is a gold mine of brilliant reasoning with special emphasis on the power and beauty of coloring proofs. Strongly recommended to both serious and recreational mathematicians on all levels of expertise. —Martin Gardner

Plane geometry is an important part in Mathematics since it appears in most Mathematics competitions. In order to solve the hard problems in the competitions, we have to have basic concepts in learning them. This is the reason why this book was written. This is a basic book in plane geometry. This book contains three main parts. The first part of it is theorems in plane geometry. In this part, there are 32 theorems. All of them are proved. Additionally, this book also provides some examples about the applications of them in solving problems. The readers should understand clearly about each theorem before they go to other parts of this book. The second part of this book is problems collections. Most of them are the problems that were appeared in the competitions. That part lists many problems. In this part, we intend the readers to try their best in solving each problem. We want the readers to apply what they have learnt in the first part of this book. The readers should know that the best way in learning Mathematics is to do it. Even we cannot solve the problems, we still gain knowledge. It helps us to be familiar in solving skill. Do not feel bad if you cannot solve them since there are only few people can solve all problems in this book without reading the solutions. The final part of this book is solutions to each problem that we listed in the second part of this book. Different from other Mathematical Olympiad books, this book provides the readers with full solutions of each problem. We try as much as we can to help readers to understand well about what they want to learn. This means that we have tried to find the easiest way in solving the problems. We hope the readers gain many techniques in solving geometry problems from this little book.

Enjoy your reading! Richard S. Hammond

Mathematical Olympiad Treasures aims at building a bridge between ordinary high school exercises and more sophisticated, intricate and abstract concepts in undergraduate mathematics. The book contains a stimulating collection of problems in the subjects of algebra, geometry, trigonometry, number theory and combinatorics. While it may be considered a sequel to "Mathematical Olympiad Challenges," the focus is on engaging a wider audience to apply techniques and strategies to real-world problems. Throughout the book students are encouraged to express their ideas, conjectures, and conclusions in writing. The goal is to help readers develop a host of new mathematical tools that will be useful beyond the classroom and in a number of disciplines.

The book "New Problems and Solutions for International Mathematical Competitions and Olympiads" provides good experiences for those students who are enthusiastic in thinking and fighting with problems that are famous in the global fields. The problems of the book have been designed ingeniously and selected carefully from thousands of potent problems and notes from many years ago up to now, as to make a basis of important key- problems which contains multiple ideas in ? Number's Theory ? Combinatorics ? Geometry ? Mathematics Analysis ? Complex Numbers Geometry and etc. I have tried to solve them in a clear way such that nearly all the steps have been explained. The problems may first be appeared as related to an obvious class whereas in the solution, lots of joint ideas are essential to solve. The feature which makes this book different from similar books is the fact that I have established a firm structure here which includes almost all dimensions necessary for both university and high school students to direct their acquired ideas and, in the terms of mathematics, to make a complete graph of them.

Authored by a leading name in mathematics, this engaging and clearly presented text leads the reader through the tactics involved in solving mathematical problems at the Mathematical Olympiad level. With numerous exercises and assuming only basic mathematics, this text is ideal for students of 14 years and above in pure mathematics.

A collection of problems put together by coaches of the U.S. International Mathematical Olympiad Team.

Vietnam has actively organized the National Competition in Mathematics and since 1962, the Vietnamese Mathematical Olympiad (VMO). On the global stage, Vietnam has also competed in the International Mathematical Olympiad (IMO) since 1974 and constantly emerged as one of the top ten. To inspire and further challenge readers, we have gathered in this book problems of various degrees of difficulty of the VMO from 1962 to 2009. The book is highly useful for high school students and teachers, coaches and instructors preparing for mathematical olympiads, as well as non-experts simply interested in having the edge over their opponents in mathematical competitions.

This book is intended as a teacher's manual and a self-study handbook for high-school or college students, and mathematical competitors. It consists mainly of problems created by the authors, with author-prepared-solutions, which were used in different national and international Mathematical Olympiads from 1984 to 2019. The book is arranged by topic and difficulty level. The book gives a broad view of mathematics and goes well beyond the elementary mathematics by providing deeper treatments of the following topics: Geometry and Trigonometry, Number theory, Algebra, Combinatorics and Calculus.

In China, lots of excellent maths students takes an active part in various maths contests and the best six senior high school students will be selected to form the IMO National Team to compete in the International Mathematical Olympiad. In the past ten years, China's IMO Team has achieved outstanding results — they have won the first place almost every year. The author is one of the senior coaches of China's IMO National Team, he is the headmaster of Shanghai senior high school which is one of the best high schools of China. In the past decade, the

students of this school have won the IMO gold medals almost every year. The author attempts to use some common characteristics of sequence and mathematical induction to fundamentally connect Math Olympiad problems to particular branches of mathematics. In doing so, the author hopes to reveal the beauty and joy involved with math exploration and at the same time, attempts to arouse readers' interest of learning math and invigorate their courage to challenge themselves with difficult problems.

Various elementary techniques for solving problems in algebra, geometry, and combinatorics are explored in this second edition of *Mathematics as Problem Solving*. Each new chapter builds on the previous one, allowing the reader to uncover new methods for using logic to solve problems. Topics are presented in self-contained chapters, with classical solutions as well as Soifer's own discoveries. With roughly 200 different problems, the reader is challenged to approach problems from different angles. *Mathematics as Problem Solving* is aimed at students from high school through undergraduate levels and beyond, educators, and the general reader interested in the methods of mathematical problem solving.

The Moscow Mathematical Olympiad has been challenging high school students with stimulating, original problems of different degrees of difficulty for over 75 years. The problems are nonstandard; solving them takes wit, thinking outside the box, and, sometimes, hours of contemplation. Some are within the reach of most mathematically competent high school students, while others are difficult even for a mathematics professor. Many mathematically inclined students have found that tackling these problems, or even just reading their solutions, is a great way to develop mathematical insight. In 2006 the Moscow Center for Continuous Mathematical Education began publishing a collection of problems from the Moscow Mathematical Olympiads, providing for each an answer (and sometimes a hint) as well as one or more detailed solutions. This volume represents the years 2000-2005. The problems and the accompanying material are well suited for math circles. They are also appropriate for problem-solving classes and practice for regional and national mathematics competitions. In the interest of fostering a greater awareness and appreciation of mathematics and its connections to other disciplines and everyday life, MSRI and the AMS are publishing books in the Mathematical Circles Library series as a service to young people, their parents and teachers, and the mathematics profession. Titles in this series are co-published with the Mathematical Sciences Research Institute (MSRI).

This book shows the approaches to solving many difficult Mathematical Olympiad and other international problems posted at the www.mathlinks.ro, the largest mathematical webpage that has most of the problems used to select the talented students of the world. At the time of this book's publication, the solutions to many of these problems are not yet available. This book is not only as much about methods of solving mathematical problems as it is about various approaches to solving the difficult problems in general. It is a first step in examining the creativity that goes into problem-solving. The real points of the book are the enumeration of problem-solving strategies and the tricks applied to solve the problems. The approaches in the book build understanding and not just methods in solving problems. This book is a must read for many math students and is useful for many teachers around the world.

The book contains problems from the first 32 British Mathematical Olympiad (BMO) papers 1965-96 and gives hints and outline solutions to each problem from 1975 onwards. An overview is given of the basic mathematical skills needed, and a list of books for further reading is provided. Working through the exercises provides a valuable source of extension and enrichment for all pupils and adults interested in mathematics.

See also *A FIRST STEP TO MATHEMATICAL OLYMPIAD PROBLEMS* The International Mathematical Olympiad (IMO) is an annual international mathematics competition held for pre-collegiate students. It is also the oldest of the international science olympiads, and competition for places is particularly fierce. This book is an amalgamation of the booklets originally

produced to guide students intending to contend for placement on their country's IMO team. See also *A First Step to Mathematical Olympiad Problems* which was published in 2009. The material contained in this book provides an introduction to the main mathematical topics covered in the IMO, which are: Combinatorics, Geometry and Number Theory. In addition, there is a special emphasis on how to approach unseen questions in Mathematics, and model the writing of proofs. Full answers are given to all questions. Though *A Second Step to Mathematical Olympiad Problems* is written from the perspective of a mathematician, it is written in a way that makes it easily comprehensible to adolescents. This book is also a must-read for coaches and instructors of mathematical competitions.

Popular Lectures in Mathematics, Volume 12: Mathematical Problems and Puzzles: From the Polish Mathematical Olympiads contains sample problems from various fields of mathematics, including arithmetic, algebra, geometry, and trigonometry. The contest for secondary school pupils known as the Mathematical Olympiad has been held in Poland every year since 1949/50. This book is composed of two main parts. Part I considers the problems and solutions about integers, polynomials, algebraic fractions and irrational experience. Part II focuses on the problems of geometry and trigonometric transformation, along with their solutions. The provided solutions aim to extend the student's knowledge of mathematics and train them in mathematical thinking. This book will prove useful to secondary school mathematics teachers and students.

This is a challenging problem-solving book in Euclidean geometry, assuming nothing of the reader other than a good deal of courage. Topics covered included cyclic quadrilaterals, power of a point, homothety, triangle centers; along the way the reader will meet such classical gems as the nine-point circle, the Simson line, the symmedian and the mixtilinear incircle, as well as the theorems of Euler, Ceva, Menelaus, and Pascal. Another part is dedicated to the use of complex numbers and barycentric coordinates, granting the reader both a traditional and computational viewpoint of the material. The final part consists of some more advanced topics, such as inversion in the plane, the cross ratio and projective transformations, and the theory of the complete quadrilateral. The exposition is friendly and relaxed, and accompanied by over 300 beautifully drawn figures. The emphasis of this book is placed squarely on the problems. Each chapter contains carefully chosen worked examples, which explain not only the solutions to the problems but also describe in close detail how one would invent the solution to begin with. The text contains a selection of 300 practice problems of varying difficulty from contests around the world, with extensive hints and selected solutions. This book is especially suitable for students preparing for national or international mathematical olympiads or for teachers looking for a text for an honor class.

This book provides a comprehensive, in-depth overview of elementary mathematics as explored in Mathematical Olympiads around the world. It expands on topics usually encountered in high school and could even be used as preparation for a first-semester undergraduate course. This second volume covers Plane Geometry, Trigonometry, Space Geometry, Vectors in the Plane, Solids and much more. As part of a collection, the book differs from other publications in this field by not being a mere selection of questions or a set of tips and tricks that applies to specific problems. It starts from the most basic theoretical principles, without being either too general or too axiomatic. Examples and problems are discussed only if they are helpful as applications of the theory. Propositions are proved in detail and subsequently applied to Olympic problems or to other problems at the Olympic level. The book also explores some of the hardest problems presented at National and International Mathematics Olympiads, as well as many essential theorems related to the content. An extensive Appendix offering hints on or full solutions for all difficult problems rounds out the book.

Hundreds of beautiful, challenging, and instructive problems from algebra, geometry,

trigonometry, combinatorics, and number theory Historical insights and asides are presented to stimulate further inquiry Emphasis is on creative solutions to open-ended problems Many examples, problems and solutions, with a user-friendly and accessible style Enhanced motivational References

This book consists only of author-created problems with author-prepared solutions (never published before) and it is intended as a teacher's manual of mathematics, a self-study handbook for high-school students and mathematical competitors interested in AMC 12 (American Mathematics Competitions). The book teaches problem solving strategies and aids to improve problem solving skills. The book includes a list of the most useful theorems and formulas for AMC 12, it also includes 14 sets of author-created AMC 12 type practice tests (350 author-created AMC 12 type problems and their detailed solutions). National Math Competition Preparation (NMCP) program of RSM used part of these 14 sets of practice tests to train students for AMC 12, as a result 75 percent of NMCP high school students qualified for AIME. The authors provide both a list of answers for all 14 sets of author-created AMC 12 type practice tests and author-prepared solutions for each problem. About the authors: Hayk Sedrakyan is an IMO medal winner, professional mathematical Olympiad coach in greater Boston area, Massachusetts, USA. He is the Dean of math competition preparation department at RSM. He has been a Professor of mathematics in Paris and has a PhD in mathematics (optimal control and game theory) from the UPMC - Sorbonne University, Paris, France. Hayk is a Doctor of mathematical sciences in USA, France, Armenia and holds three master's degrees in mathematics from institutions in Germany, Austria, Armenia and has spent a small part of his PhD studies in Italy. Hayk Sedrakyan has worked as a scientific researcher for the European Commission (sadco project) and has been one of the Team Leaders at Harvard-MIT Mathematics Tournament (HMMT). He took part in the International Mathematical Olympiads (IMO) in United Kingdom, Japan and Greece. Hayk has been elected as the President of the students' general assembly and a member of the management board of Cite Internationale Universitaire de Paris (10,000 students, 162 different nationalities) and the same year they were nominated for the Nobel Peace Prize. Nairi Sedrakyan is involved in national and international mathematical Olympiads having been the President of Armenian Mathematics Olympiads and a member of the IMO problem selection committee. He is the author of the most difficult problem ever proposed in the history of the International Mathematical Olympiad (IMO), 5th problem of 37th IMO. This problem is considered to be the hardest problems ever in the IMO because none of the members of the strongest teams (national Olympic teams of China, USA, Russia) succeeded to solve it correctly and because national Olympic team of China (the strongest team in the IMO) obtained a cumulative result equal to 0 points and was ranked 6th in the final ranking of the countries instead of the usual 1st or 2nd place. The British 2014 film *X+Y*, released in the USA as *A Brilliant Young Mind*, inspired by the film *Beautiful Young Minds* (focuses on an English mathematical genius chosen to represent the United Kingdom at the IMO) also states that this problem is the hardest problem ever proposed in the history of the IMO (minutes 9:40-10:30). Nairi Sedrakyan's students (including his son Hayk Sedrakyan) have received 20 medals in the International Mathematical Olympiad (IMO), including Gold and Silver medals.

The International Mathematical Olympiad (IMO) is a competition for high school students. China has taken part in the IMO 21 times since 1985 and has won the top ranking for countries 14 times, with a multitude of golds for individual students. The six students China has sent every year were selected from 20 to 30 students among approximately 130 students who took part in the annual China Mathematical Competition during the winter months. This volume comprises a collection of original problems with solutions that China used to train their Olympiad team in the years from 2006 to 2008. Mathematical Olympiad problems with solutions for the years 2002-2006 appear in an earlier volume, *Mathematical Olympiad in*

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Over 300 challenging problems in algebra, arithmetic, elementary number theory and trigonometry, selected from Mathematical Olympiads held at Moscow University. Only high school math needed. Includes complete solutions. Features 27 black-and-white illustrations. 1962 edition.

A unique collection of competition problems from over twenty major national and international mathematical competitions for high school students. Written for trainers and participants of contests of all levels up to the highest level, this will appeal to high school teachers conducting a mathematics club who need a range of simple to complex problems and to those instructors wishing to pose a "problem of the week", thus bringing a creative atmosphere into the classrooms. Equally, this is a must-have for individuals interested in solving difficult and challenging problems. Each chapter starts with typical examples illustrating the central concepts and is followed by a number of carefully selected problems and their solutions. Most of the solutions are complete, but some merely point to the road leading to the final solution. In addition to being a valuable resource of mathematical problems and solution strategies, this is the most complete training book on the market.

This book provides a comprehensive, in-depth overview of elementary mathematics as explored in Mathematical Olympiads around the world. It expands on topics usually encountered in high school and could even be used as preparation for a first-semester undergraduate course. This third and last volume covers Counting, Generating Functions, Graph Theory, Number Theory, Complex Numbers, Polynomials, and much more. As part of a collection, the book differs from other publications in this field by not being a mere selection of questions or a set of tips and tricks that applies to specific problems. It starts from the most basic theoretical principles, without being either too general or too axiomatic. Examples and problems are discussed only if they are helpful as applications of the theory. Propositions are proved in detail and subsequently applied to Olympic problems or to other problems at the Olympic level. The book also explores some of the hardest problems presented at National and International Mathematics Olympiads, as well as many essential theorems related to the content. An extensive Appendix offering hints on or full solutions for all difficult problems rounds out the book.

In July 2009 Germany hosted the 50th International Mathematical Olympiad (IMO). For the very first time the number of participating countries exceeded 100, with 104 countries from all continents. Celebrating the 50th anniversary of the IMO provides an ideal opportunity to look back over the past five decades and to review its development to become a worldwide event. This book is a report about the 50th IMO as well as the IMO history. A lot of data about all the 50 IMOs are included. We list the most successful contestants, the results of the 50 Olympiads and the 112 countries that have

ever taken part. It is impressive to see that many of the world's leading research mathematicians were among the most successful IMO participants in their youth. Six of them gave presentations at a special celebration: Bollobás, Gowers, Lovász, Smirnov, Tao and Yoccoz. This book is aimed at students in the IMO age group and all those who have interest in this worldwide leading competition for highschool students. Contained here are solutions to challenging problems from algebra, geometry, combinatorics and number theory featured in the earlier book, together with selected questions (without solutions) from national and regional Olympiads given during the year 2000. Intended for the serious student/problem solver, these books can help to improve performance in the Mathematical Olympiad competition. However, for those not entering the competition, there is much to challenge any mathematician, even those with advanced degrees. Different nations have different mathematical cultures, so you will find that some of the questions are extremely difficult and some rather easy. There are a wide variety of problems especially from those countries that have often done well in the IMO. Anyone interested in mathematical problem solving will encounter some beautiful mathematics in the pages of this book. If you are up to a real challenge, take some of these problems on!

This updated printing of the first edition of Colorado Mathematical Olympiad: the First Twenty Years and Further Explorations gives the interesting history of the competition as well as an outline of all the problems and solutions that have been created for the contest over the years. Many of the essay problems were inspired by Russian mathematical folklore and written to suit the young audience; for example, the 1989 Sugar problem was written in a pleasant Lewis Carroll-like story. Some other entertaining problems involve olde Victorian map colourings, King Authur and the knights of the round table, rooks in space, Santa Claus and his elves painting planes, football for 23, and even the Colorado Springs subway system.

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Collection of nearly 200 unusual problems dealing with congruence and parallelism, the Pythagorean theorem, circles, area relationships, Ptolemy and the cyclic quadrilateral, collinearity and concurrency and more. Arranged in order of difficulty. Detailed solutions.

This book provides a comprehensive, in-depth overview of elementary mathematics as explored in Mathematical Olympiads around the world. It expands on topics usually encountered in high school and could even be used as preparation for a first-semester

undergraduate course. This first volume covers Real Numbers, Functions, Real Analysis, Systems of Equations, Limits and Derivatives, and much more. As part of a collection, the book differs from other publications in this field by not being a mere selection of questions or a set of tips and tricks that applies to specific problems. It starts from the most basic theoretical principles, without being either too general or too axiomatic. Examples and problems are discussed only if they are helpful as applications of the theory. Propositions are proved in detail and subsequently applied to Olympic problems or to other problems at the Olympic level. The book also explores some of the hardest problems presented at National and International Mathematics Olympiads, as well as many essential theorems related to the content. An extensive Appendix offering hints on or full solutions for all difficult problems rounds out the book. This new volume of the Mathematical Olympiad Series focuses on the topic of geometry. Basic and advanced theorems commonly seen in Mathematical Olympiad are introduced and illustrated with plenty of examples. Special techniques in solving various types of geometrical problems are also introduced, while the authors elaborate extensively on how to acquire an insight and develop strategies in tackling difficult geometrical problems. This book is suitable for any reader with elementary geometrical knowledge at the lower secondary level. Each chapter includes sufficient scaffolding and is comprehensive enough for the purpose of self-study. Readers who complete the chapters on the basic theorems and techniques would acquire a good foundation in geometry and may attempt to solve many geometrical problems in various mathematical competitions. Meanwhile, experienced contestants in Mathematical Olympiad competitions will find a large collection of problems pitched at competitions at the international level, with opportunities to practise and sharpen their problem-solving skills in geometry. Request Inspection Copy

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The Hard Mathematical Olympiad Problems and Their Solutions

BETHANY MACDONALD HAS TRAINED SIX LONG YEARS FOR THIS MOMENT. SHE'LL TRY TO SOLVE FIVE QUESTIONS IN THREE HOURS, FOR ONE IMPROBABLE DREAM. THE DREAM OF REPRESENTING HER COUNTRY, AND BECOMING A MATH OLYMPIAN. As a small-town girl in Nova Scotia bullied for liking numbers more than boys, and lacking the encouragement of her unsupportive single mother who frowns at her daughter's unrealistic ambition, Bethany's road to the International Math Olympiad has been marked by numerous challenges. Through persistence, perseverance, and the support of innovative mentors who inspire her with a love of learning, Bethany confronts these challenges and develops the creativity and confidence to reach her potential. In training to become a world-champion "mathlete", Bethany discovers the heart of mathematics – a subject that's not about memorizing formulas, but rather about problem-solving and detecting patterns to uncover truth, as well as learning how to apply the deep and unexpected connections of mathematics to

every aspect of her life, including athletics, spirituality, and environmental sustainability. As Bethany reflects on her long journey and envisions her exciting future, she realizes that she has shattered the misguided stereotype that only boys can excel in math, and discovers a sense of purpose that through mathematics, she can and she will make an extraordinary contribution to society.

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"The IMO Compendium" is the ultimate collection of challenging high-school-level mathematics problems and is an invaluable resource not only for high-school students preparing for mathematics competitions, but for anyone who loves and appreciates mathematics. The International Mathematical Olympiad (IMO), nearing its 50th anniversary, has become the most popular and prestigious competition for high-school students interested in mathematics. Only six students from each participating country are given the honor of participating in this competition every year. The IMO represents not only a great opportunity to tackle interesting and challenging mathematics problems, it also offers a way for high school students to measure up with students from the rest of the world. Until the first edition of this book appearing in 2006, it has been almost impossible to obtain a complete collection of the problems proposed at the IMO in book form. "The IMO Compendium" is the result of a collaboration between four former IMO participants from Yugoslavia, now Serbia and Montenegro, to rescue these problems from old and scattered manuscripts, and produce the ultimate source of IMO practice problems. This book attempts to gather all the problems and solutions appearing on the IMO through 2009. This second edition contains 143 new problems, picking up where the 1959-2004 edition has left off.

Over 300 unusual problems, ranging from easy to difficult, involving equations and inequalities, Diophantine equations, number theory, quadratic equations, logarithms, more. Detailed solutions, as well as brief answers, for all problems are provided.

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