

Algebra With Galois Theory American Mathematical Society

This book is the second volume of an intensive “Russian-style” two-year undergraduate course in abstract algebra, and introduces readers to the basic algebraic structures – fields, rings, modules, algebras, groups, and categories – and explains the main principles of and methods for working with them. The course covers substantial areas of advanced combinatorics, geometry, linear and multilinear algebra, representation theory, category theory, commutative algebra, Galois theory, and algebraic geometry – topics that are often overlooked in standard undergraduate courses. This textbook is based on courses the author has conducted at the Independent University of Moscow and at the Faculty of Mathematics in the Higher School of Economics. The main content is complemented by a wealth of exercises for class discussion, some of which include comments and hints, as well as problems for independent study.

This volume is based on talks given at the Workshop on Categorical Structures for Descent and Galois Theory, Hopf Algebras, and Semiabelian Categories held at The Fields Institute for Research in Mathematical Sciences (Toronto, ON, Canada). The meeting brought together researchers working in these interrelated areas. This collection of survey and research papers gives an up-to-date account of the many current connections among Galois theories, Hopf algebras, and semiabelian categories. The book features articles by leading researchers on a wide range of themes, specifically, abstract Galois theory, Hopf algebras, and categorical

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structures, in particular quantum categories and higher-dimensional structures. Articles are suitable for graduate students and researchers, specifically those interested in Galois theory and Hopf algebras and their categorical unification.

The present text was first published in 1947 by the Courant Institute of Mathematical Sciences of New York University. Published under the title *Modern Higher Algebra. Galois Theory*, it was based on lectures by Emil Artin and written by Albert A. Blank. This volume became one of the most popular in the series of lecture notes published by Courant. Many instructors used the book as a textbook, and it was popular among students as a supplementary text as well as a primary textbook. Because of its popularity, Courant has republished the volume under the new title *Algebra with Galois Theory*.

In the fall of 1990, I taught Math 581 at New Mexico State University for the first time. This course on field theory is the first semester of the year-long graduate algebra course here at NMSU. In the back of my mind, I thought it would be nice someday to write a book on field theory, one of my favorite mathematical subjects, and I wrote a crude form of lecture notes that semester. Those notes sat undisturbed for three years until late in 1993 when I finally made the decision to turn the notes into a book. The notes were greatly expanded and rewritten, and they were in a form sufficient to be used as the text for Math 581 when I taught it again in the fall of 1994. Part of my desire to write a textbook was due to the nonstandard format of our graduate algebra sequence. The first semester of our sequence is field theory. Our graduate students generally pick up group and ring theory in a senior-level course prior to taking field theory. Since we start with field theory, we would have to jump into the middle of most graduate algebra textbooks. This can make reading the text difficult by not knowing what the

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author did before the field theory chapters. Therefore, a book devoted to field theory is desirable for us as a text. While there are a number of field theory books around, most of these were less complete than I wanted.

Galois theory is considered one of the most beautiful subjects in mathematics, but it is hard to appreciate this fact fully without seeing specific examples. Numerous examples are therefore included throughout this text, in the hope that they will lead to a deeper understanding and genuine appreciation of the more abstract and advanced literature on Galois theory.

Clearly presented discussions of fields, vector spaces, homogeneous linear equations, extension fields, polynomials, algebraic elements, as well as sections on solvable groups, permutation groups, solution of equations by radicals, and other concepts. 1966 edition.

This insightful book combines the history, pedagogy, and popularization of algebra to present a unified discussion of the subject. *Classical Algebra* provides a complete and contemporary perspective on classical polynomial algebra through the exploration of how it was developed and how it exists today. With a focus on prominent areas such as the numerical solutions of equations, the systematic study of equations, and Galois theory, this book facilitates a thorough understanding of algebra and illustrates how the concepts of modern algebra originally developed from classical algebraic precursors. This book successfully ties together the disconnect between classical and modern algebra and provides readers with answers to many fascinating questions that typically go unexamined, including: What is algebra about? How did it arise? What uses does it have? How did it develop? What problems and issues have occurred in its history? How were these problems and issues resolved? The author answers these questions and more, shedding light on a rich history of the subject—from ancient

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and medieval times to the present. Structured as eleven "lessons" that are intended to give the reader further insight on classical algebra, each chapter contains thought-provoking problems and stimulating questions, for which complete answers are provided in an appendix. Complemented with a mixture of historical remarks and analyses of polynomial equations throughout, *Classical Algebra: Its Nature, Origins, and Uses* is an excellent book for mathematics courses at the undergraduate level. It also serves as a valuable resource to anyone with a general interest in mathematics.

This textbook offers a unique introduction to classical Galois theory through many concrete examples and exercises of varying difficulty (including computer-assisted exercises). In addition to covering standard material, the book explores topics related to classical problems such as Galois' theorem on solvable groups of polynomial equations of prime degrees, Nagell's proof of non-solvability by radicals of quintic equations, Tschirnhausen's transformations, lunes of Hippocrates, and Galois' resolvents. Topics related to open conjectures are also discussed, including exercises related to the inverse Galois problem and cyclotomic fields. The author presents proofs of theorems, historical comments and useful references alongside the exercises, providing readers with a well-rounded introduction to the subject and a gateway to further reading. A valuable reference and a rich source of exercises with sample solutions, this book will be useful to both students and lecturers. Its original concept makes it particularly suitable for self-study.

Galois Theory, the theory of polynomial equations and their solutions, is one of the most fascinating and beautiful subjects of pure mathematics. Using group theory and field theory, it provides a complete answer to the problem of the solubility of polynomial

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equations by radicals: that is, determining when and how a polynomial equation can be solved by repeatedly extracting roots using elementary algebraic operations. This textbook contains a fully detailed account of Galois Theory and the algebra that it needs and is suitable both for those following a course of lectures and the independent reader (who is assumed to have no previous knowledge of Galois Theory). The second edition has been significantly revised and re-ordered; the first part develops the basic algebra that is needed, and the second a comprehensive account of Galois Theory. There are applications to ruler-and-compass constructions, and to the solution of classical mathematical problems of ancient times. There are new exercises throughout, and carefully-selected examples will help the reader develop a clear understanding of the mathematical theory.

This is a book of problems in abstract algebra for strong undergraduates or beginning graduate students. It can be used as a supplement to a course or for self-study. The book provides more variety and more challenging problems than are found in most algebra textbooks. It is intended for students wanting to enrich their learning of mathematics by tackling problems that take some thought and effort to solve. The book contains problems on groups (including the Sylow Theorems, solvable groups, presentation of groups by generators and relations, and structure and duality for finite abelian groups); rings (including basic ideal theory and factorization in integral domains and Gauss's Theorem); linear algebra (emphasizing linear transformations, including

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canonical forms); and fields (including Galois theory). Hints to many problems are also included.

Suitable for advanced undergraduates and graduate students in mathematics and computer science, this precise, self-contained treatment of Galois theory features detailed proofs and complete solutions to exercises. Originally published in French as *Algèbre — Polynômes, théorie de Galois et applications informatiques*, this 2017 Dover Aurora edition marks the volume's first English-language publication. The three-part treatment begins by providing the essential introduction to Galois theory. The second part is devoted to the algebraic, normal, and separable Galois extensions that constitute the center of the theory and examines abelian, cyclic, cyclotomic, and radical extensions. This section enables readers to acquire a comprehensive understanding of the Galois group of a polynomial. The third part deals with applications of Galois theory, including excellent discussions of several important real-world applications of these ideas, including cryptography and error-control coding theory. Symbolic computation via the Maple computer algebra system is incorporated throughout the text (though other software of symbolic computation could be used as well), along with a large number of very interesting exercises with full solutions.

Praise for the First Edition ". . .will certainly fascinate anyone interested in abstractalgebra: a remarkable book!" —*Monatshefte für Mathematik* Galois theory is one of the most established topics in mathematics, with historical roots that led to the

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development of many central concepts in modern algebra, including groups and fields. Covering classic applications of the theory, such as solvability by radicals, geometric constructions, and finite fields, *Galois Theory, Second Edition* delves into novel topics like Abel's theory of Abelian equations, casus irreducibilis, and the Galois theory of origami. In addition, this book features detailed treatments of several topics not covered in standard texts on Galois theory, including: The contributions of Lagrange, Galois, and Kronecker How to compute Galois groups Galois's results about irreducible polynomials of prime or prime-squared degree Abel's theorem about geometric constructions on the lemniscates Galois groups of quartic polynomials in all characteristics Throughout the book, intriguing Mathematical Notes and Historical Notes sections clarify the discussed ideas and the historical context; numerous exercises and examples use Maple and Mathematica to showcase the computations related to Galois theory; and extensive references have been added to provide readers with additional resources for further study. *Galois Theory, Second Edition* is an excellent book for courses on abstract algebra at the upper-undergraduate and graduate levels. The book also serves as an interesting reference for anyone with a general interest in Galois theory and its contributions to the field of mathematics.

The quadratic formula for the solution of quadratic equations was discovered independently by scholars in many ancient cultures and is familiar to everyone. Less well known are formulas for solutions of cubic and quartic equations whose discovery

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was the high point of 16th century mathematics. Their study forms the heart of this book, as part of the broader theme that a polynomial's coefficients can be used to obtain detailed information on its roots. The book is designed for self-study, with many results presented as exercises and some supplemented by outlines for solution. The intended audience includes in-service and prospective secondary mathematics teachers, high school students eager to go beyond the standard curriculum, undergraduates who desire an in-depth look at a topic they may have unwittingly skipped over, and the mathematically curious who wish to do some work to unlock the mysteries of this beautiful subject.

Galois theory has such close analogies with the theory of coverings that algebraists use a geometric language to speak of field extensions, while topologists speak of "Galois coverings". This book endeavors to develop these theories in a parallel way, starting with that of coverings, which better allows the reader to make images. The authors chose a plan that emphasizes this parallelism. The intention is to allow to transfer to the algebraic framework of Galois theory the geometric intuition that one can have in the context of coverings. This book is aimed at graduate students and mathematicians curious about a non-exclusively algebraic view of Galois theory.

Galois theory is the culmination of a centuries-long search for a solution to the classical problem of solving algebraic equations by radicals. In this book, Bewersdorff follows the historical development of the theory, emphasizing concrete examples along the way. As

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a result, many mathematical abstractions are now seen as the natural consequence of particular investigations. Few prerequisites are needed beyond general college mathematics, since the necessary ideas and properties of groups and fields are provided as needed. Results in Galois theory are formulated first in a concrete, elementary way, then in the modern form. Each chapter begins with a simple question that gives the reader an idea of the nature and difficulty of what lies ahead. The applications of the theory to geometric constructions, including the ancient problems of squaring the circle, duplicating the cube, and trisecting an angle, and the construction of regular n -gons are also presented. This book is suitable for undergraduates and beginning graduate students.

Combining a concrete perspective with an exploration-based approach, *Exploratory Galois Theory* develops Galois theory at an entirely undergraduate level. The text grounds the presentation in the concept of algebraic numbers with complex approximations and assumes of its readers only a first course in abstract algebra. For readers with Maple or Mathematica, the text introduces tools for hands-on experimentation with finite extensions of the rational numbers, enabling a familiarity never before available to students of the subject. The text is appropriate for traditional lecture courses, for seminars, or for self-paced independent study by undergraduates and graduate students.

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classical problem of solving algebraic equations by radicals. In this book, Bewersdorff follows the historical development of the theory, emphasizing concrete examples along the way. As a result, many mathematical abstractions are now seen as the natural consequence of particular investigations. Few prerequisites are needed beyond general college mathematics, since the necessary ideas and properties of groups and fields are provided as needed. Results in Galois theory are formulated first in a concrete, elementary way, then in the modern form. Each chapter begins with a simple question that gives the reader an idea of the nature and difficulty of what lies ahead. The applications of the theory to geometric constructions, including the ancient problems of squaring the circle, duplicating the cube, and trisecting the angle, and the construction of regular n -gons are also presented. This new edition contains an additional chapter as well as twenty facsimiles of milestones of classical algebra. It is suitable for undergraduates and graduate students, as well as teachers and mathematicians seeking a historical and stimulating perspective on the field. Lucid coverage of the major theories of abstract algebra, with helpful illustrations and exercises included throughout. Unabridged, corrected republication of the work originally published 1971. Bibliography. Index. Includes 24 tables and figures.

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This textbook, based on lectures given over a period of years at Cambridge, is a detailed and thorough introduction to Galois theory.

This book provides a detailed and largely self-contained description of various classical and new results on solvability and unsolvability of equations in explicit form. In particular, it offers a complete exposition of the relatively new area of topological Galois theory, initiated by the author. Applications of Galois theory to solvability of algebraic equations by radicals, basics of Picard–Vessiot theory, and Liouville's results on the class of functions representable by quadratures are also discussed. A unique feature of this book is that recent results are presented in the same elementary manner as classical Galois theory, which will make the book useful and interesting to readers with varied backgrounds in mathematics, from undergraduate students to researchers. In this English-language edition, extra material has been added (Appendices A–D), the last two of which were written jointly with Yura Burda.

Survey and research papers in this volume are based on talks given at a workshop held at The Fields Institute for Research in the Mathematical Sciences (Toronto, ON, Canada). It provides an up-to-date account by leading researchers on the many current connections among Galois theories, Hopf algebras, and semiabelian categories.

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This monograph provides a self-contained presentation of the foundations of finite fields, including a detailed treatment of their algebraic closures. It also covers important advanced topics which are not yet found in textbooks: the primitive normal basis theorem, the existence of primitive elements in affine hyperplanes, and the Niederreiter method for factoring polynomials over finite fields. We give streamlined and/or clearer proofs for many fundamental results and treat some classical material in an innovative manner. In particular, we emphasize the interplay between arithmetical and structural results, and we introduce Berlekamp algebras in a novel way which provides a deeper understanding of Berlekamp's celebrated factorization algorithm. The book provides a thorough grounding in finite field theory for graduate students and researchers in mathematics. In view of its emphasis on applicable and computational aspects, it is also useful for readers working in information and communication engineering, for instance, in signal processing, coding theory, cryptography or computer science.--

Thinking Algebraically presents the insights of abstract algebra in a welcoming and accessible way. It succeeds in combining the advantages of rings-first and groups-first approaches while avoiding the disadvantages. After an historical overview, the first chapter studies familiar examples and elementary properties of

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groups and rings simultaneously to motivate the modern understanding of algebra. The text builds intuition for abstract algebra starting from high school algebra. In addition to the standard number systems, polynomials, vectors, and matrices, the first chapter introduces modular arithmetic and dihedral groups. The second chapter builds on these basic examples and properties, enabling students to learn structural ideas common to rings and groups: isomorphism, homomorphism, and direct product. The third chapter investigates introductory group theory. Later chapters delve more deeply into groups, rings, and fields, including Galois theory, and they also introduce other topics, such as lattices. The exposition is clear and conversational throughout. The book has numerous exercises in each section as well as supplemental exercises and projects for each chapter. Many examples and well over 100 figures provide support for learning. Short biographies introduce the mathematicians who proved many of the results. The book presents a pathway to algebraic thinking in a semester- or year-long algebra course.

From the reviews: "This is a great book, which will hopefully become a classic in the subject of differential Galois theory. [...] the specialist, as well as the novice, have long been missing an introductory book covering also specific and advanced research topics. This gap is filled by the volume under review, and

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more than satisfactorily." *Mathematical Reviews*

Algebra and Tiling is a book about how to cover surfaces with shapes.

Group theory is the branch of mathematics that studies symmetry, found in crystals, art, architecture, music and many other contexts, but its beauty is lost on students when it is taught in a technical style that is difficult to understand. *Visual Group Theory* assumes only a high school mathematics background and covers a typical undergraduate course in group theory from a thoroughly visual perspective. The more than 300 illustrations in *Visual Group Theory* bring groups, subgroups, homomorphisms, products, and quotients into clear view. Every topic and theorem is accompanied with a visual demonstration of its meaning and import, from the basics of groups and subgroups through advanced structural concepts such as semidirect products and Sylow theory.

Focusing on basics of algebraic theory, this text presents detailed explanations of integral functions, permutations, and groups as well as Lagrange and Galois theory. Many numerical examples with complete solutions. 1930 edition.

Explore the foundations and modern applications of Galois theory Galois theory is widely regarded as one of the most elegant areas of mathematics. *A Classical Introduction to Galois Theory* develops the topic from a historical perspective, with an emphasis on the solvability of polynomials by radicals. The book provides a gradual transition from the computational methods typical of early literature on the subject to the more abstract approach that characterizes most contemporary expositions. The author provides an easily-accessible presentation of fundamental notions such as roots of unity, minimal polynomials, primitive elements, radical extensions, fixed fields, groups of automorphisms, and solvable series. As a

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result, their role in modern treatments of Galois theory is clearly illuminated for readers. Classical theorems by Abel, Galois, Gauss, Kronecker, Lagrange, and Ruffini are presented, and the power of Galois theory as both a theoretical and computational tool is illustrated through: A study of the solvability of polynomials of prime degree Development of the theory of periods of roots of unity Derivation of the classical formulas for solving general quadratic, cubic, and quartic polynomials by radicals Throughout the book, key theorems are proved in two ways, once using a classical approach and then again utilizing modern methods. Numerous worked examples showcase the discussed techniques, and background material on groups and fields is provided, supplying readers with a self-contained discussion of the topic. A Classical Introduction to Galois Theory is an excellent resource for courses on abstract algebra at the upper-undergraduate level. The book is also appealing to anyone interested in understanding the origins of Galois theory, why it was created, and how it has evolved into the discipline it is today.

This book is based on a course given by the author at Harvard University in the fall semester of 1988. The course focused on the inverse problem of Galois Theory: the construction of field extensions having a given finite group as Galois group. In the first part of the book, classical methods and results, such as the Scholz and Reichardt constructi

Differential Galois theory studies solutions of differential equations over a differential base field. In much the same way that ordinary Galois theory is the theory of field extensions generated by solutions of (one variable) polynomial equations, differential Galois theory looks at the nature of the differential field extension generated by the solutions of differential equations. An additional feature is that the corresponding differential Galois groups (of automorphisms of the

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extension fixing the base and commuting with the derivation) are algebraic groups. This book deals with the differential Galois theory of linear homogeneous differential equations, whose differential Galois groups are algebraic matrix groups. In addition to providing a convenient path to Galois theory, this approach also leads to the constructive solution of the inverse problem of differential Galois theory for various classes of algebraic groups. Providing a self-contained development and many explicit examples, this book provides a unique approach to differential Galois theory and is suitable as a textbook at the advanced graduate level.

This graduate textbook offers an introduction to modern methods in number theory. It gives a complete account of the main results of class field theory as well as the Poitou-Tate duality theorems, considered crowning achievements of modern number theory. Assuming a first graduate course in algebra and number theory, the book begins with an introduction to group and Galois cohomology. Local fields and local class field theory, including Lubin-Tate formal group laws, are covered next, followed by global class field theory and the description of abelian extensions of global fields. The final part of the book gives an accessible yet complete exposition of the Poitou-Tate duality theorems. Two appendices cover the necessary background in homological algebra and the analytic theory of Dirichlet L-series, including the Artin density theorem. Based on several advanced courses given by the author, this textbook has been written for graduate students. Including complete proofs and numerous exercises, the book will also appeal to more experienced mathematicians, either as a text to learn the subject or as a reference.

Differential Galois theory is an important, fast developing area which appears more and more in graduate courses since it mixes fundamental objects from many different areas of

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mathematics in a stimulating context. For a long time, the dominant approach, usually called Picard-Vessiot Theory, was purely algebraic. This approach has been extensively developed and is well covered in the literature. An alternative approach consists in tagging algebraic objects with transcendental information which enriches the understanding and brings not only new points of view but also new solutions. It is very powerful and can be applied in situations where the Picard-Vessiot approach is not easily extended. This book offers a hands-on transcendental approach to differential Galois theory, based on the Riemann-Hilbert correspondence. Along the way, it provides a smooth, down-to-earth introduction to algebraic geometry, category theory and tannakian duality. Since the book studies only complex analytic linear differential equations, the main prerequisites are complex function theory, linear algebra, and an elementary knowledge of groups and of polynomials in many variables. A large variety of examples, exercises, and theoretical constructions, often via explicit computations, offers first-year graduate students an accessible entry into this exciting area.

This book is the second part of the new edition of *Advanced Modern Algebra* (the first part published as *Graduate Studies in Mathematics, Volume 165*). Compared to the previous edition, the material has been significantly reorganized and many sections have been rewritten. The book presents many topics mentioned in the first part in greater depth and in more detail. The five chapters of the book are devoted to group theory, representation theory, homological algebra, categories, and commutative algebra, respectively. The book can be used as a text for a second abstract algebra graduate course, as a source of additional material to a first abstract algebra graduate course, or for self-study.

This collection consists of original work on Galois theory, rings and algebras, algebraic

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geometry, group representations, algebraic K -theory and some of their applications. This book discusses major topics in Galois theory and advanced linear algebra, including canonical forms. Divided into four chapters and presenting numerous new theorems, it serves as an easy-to-understand textbook for undergraduate students of advanced linear algebra, and helps students understand other courses, such as Riemannian geometry. The book also discusses key topics including Cayley–Hamilton theorem, Galois groups, Sylvester’s law of inertia, Eisenstein criterion, and solvability by radicals. Readers are assumed to have a grasp of elementary properties of groups, rings, fields, and vector spaces, and familiarity with the elementary properties of positive integers, inner product space of finite dimension and linear transformations is beneficial.

The book gives a detailed account of the development of the theory of algebraic equations, from its origins in ancient times to its completion by Galois in the nineteenth century. The appropriate parts of works by Cardano, Lagrange, Vandermonde, Gauss, Abel, and Galois are reviewed and placed in their historical perspective, with the aim of conveying to the reader a sense of the way in which the theory of algebraic equations has evolved and has led to such basic mathematical notions as "group" and "field". A brief discussion of the fundamental theorems of modern Galois theory and complete proofs of the quoted results are provided, and the material is organized in such a way that the more technical details can be skipped by readers who are interested primarily in a broad survey of the theory. In this second edition, the exposition has been improved throughout and the chapter on Galois has been entirely rewritten to better reflect Galois' highly innovative contributions. The text now follows more closely Galois' memoir, resorting as sparsely as possible to anachronistic modern notions such

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as field extensions. The emerging picture is a surprisingly elementary approach to the solvability of equations by radicals, and yet is unexpectedly close to some of the most recent methods of Galois theory.

Foundations of Galois Theory is an introduction to group theory, field theory, and the basic concepts of abstract algebra. The text is divided into two parts. Part I presents the elements of Galois Theory, in which chapters are devoted to the presentation of the elements of field theory, facts from the theory of groups, and the applications of Galois Theory. Part II focuses on the development of general Galois Theory and its use in the solution of equations by radicals. Equations that are solvable by radicals; the construction of equations solvable by radicals; and the unsolvability by radicals of the general equation of degree $n \geq 5$ are discussed as well. Mathematicians, physicists, researchers, and students of mathematics will find this book highly useful.

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