

Chapter 13 Field Theory 510

- 13.1 Basic Theory of Field Extensions 510
- 13.2 Algebraic Extensions 520
- 13.3 Classical Straightedge and Compass Constructions 531
- 13.4 Splitting Fields and Algebraic Closures 536
- 13.5 Separable and Inseparable Extensions 545
- 13.6 Cyclotomic Polynomials and Extensions 552

Chapter 14 Galois Theory 558

- 14.1 Basic Definitions 558
- 14.2 The Fundamental Theorem of Galois Theory 567
- 14.3 Finite Fields 585
- 14.4 Composite Extensions and Simple Extensions 591
- 14.5 Cyclotomic Extensions and Abelian Extensions over \mathbb{Q} 596
- 14.6 Galois Groups of Polynomials 606
- 14.7 Solvable and Radical Extensions: Insolvability of the Quintic 625
- 14.8 Computation of Galois Groups over \mathbb{Q} 640
- 14.9 Transcendental Extensions, Inseparable Extensions, Infinite Galois Groups 645

**Part V – AN INTRODUCTION TO COMMUTATIVE RINGS,
ALGEBRAIC GEOMETRY, AND
HOMOLOGICAL ALGEBRA 655**

Chapter 15 Commutative Rings and Algebraic Geometry 656

- 15.1 Noetherian Rings and Affine Algebraic Sets 656
- 15.2 Radicals and Affine Varieties 673
- 15.3 Integral Extensions and Hilbert's Nullstellensatz 691
- 15.4 Localization 706
- 15.5 The Prime Spectrum of a Ring 731

**Chapter 16 Artinian Rings, Discrete Valuation Rings, and
Dedekind Domains 750**

- 16.1 Artinian Rings 750
- 16.2 Discrete Valuation Rings 755
- 16.3 Dedekind Domains 764

Chapter 17 Introduction to Homological Algebra and Group Cohomology 776

- 17.1 Introduction to Homological Algebra—Ext and Tor 777
- 17.2 The Cohomology of Groups 798
- 17.3 Crossed Homomorphisms and $H^1(G, A)$ 814
- 17.4 Group Extensions, Factor Sets and $H^2(G, A)$ 824

Part VI – INTRODUCTION TO THE REPRESENTATION THEORY OF FINITE GROUPS 839

Chapter 18 Representation Theory and Character Theory 840

- 18.1 Linear Actions and Modules over Group Rings 840
- 18.2 Wedderburn's Theorem and Some Consequences 854
- 18.3 Character Theory and the Orthogonality Relations 864

Chapter 19 Examples and Applications of Character Theory 880

- 19.1 Characters of Groups of Small Order 880
- 19.2 Theorems of Burnside and Hall 886
- 19.3 Introduction to the Theory of Induced Characters 892

Appendix I: Cartesian Products and Zorn's Lemma 905

Appendix II: Category Theory 911

Index 919

Preface to the Third Edition

The principal change from the second edition is the addition of Gröbner bases to this edition. The basic theory is introduced in a new Section 9.6. Applications to solving systems of polynomial equations (elimination theory) appear at the end of this section, rounding it out as a self-contained foundation in the topic. Additional applications and examples are then woven into the treatment of affine algebraic sets and k -algebra homomorphisms in Chapter 15. Although the theory in the latter chapter remains independent of Gröbner bases, the new applications, examples and computational techniques significantly enhance the development, and we recommend that Section 9.6 be read either as a segue to or in parallel with Chapter 15. A wealth of exercises involving Gröbner bases, both computational and theoretical in nature, have been added in Section 9.6 and Chapter 15. Preliminary exercises on Gröbner bases can (and should, as an aid to understanding the algorithms) be done by hand, but more extensive computations, and in particular most of the use of Gröbner bases in the exercises in Chapter 15, will likely require computer assisted computation.

Other changes include a streamlining of the classification of simple groups of order 168 (Section 6.2), with the addition of a uniqueness proof via the projective plane of order 2. Some other proofs or portions of the text have been revised slightly. A number of new exercises have been added throughout the book, primarily at the ends of sections in order to preserve as much as possible the numbering schemes of earlier editions. In particular, exercises have been added on free modules over noncommutative rings (10.3), on Krull dimension (15.3), and on flat modules (10.5 and 17.1).

As with previous editions, the text contains substantially more than can normally be covered in a one year course. A basic introductory (one year) course should probably include Part I up through Section 5.3, Part II through Section 9.5, Sections 10.1, 10.2, 10.3, 11.1, 11.2 and Part IV. Chapter 12 should also be covered, either before or after Part IV. Additional topics from Chapters 5, 6, 9, 10 and 11 may be interspersed in such a course, or covered at the end as time permits.

Sections 10.4 and 10.5 are at a slightly higher level of difficulty than the initial sections of Chapter 10, and can be deferred on a first reading for those following the text sequentially. The latter section on properties of exact sequences, although quite long, maintains coherence through a parallel treatment of three basic functors in respective subsections.

Beyond the core material, the third edition provides significant flexibility for students and instructors wishing to pursue a number of important areas of modern algebra,

either in the form of independent study or courses. For example, well integrated one-semester courses for students with some prior algebra background might include the following: Section 9.6 and Chapters 15 and 16; or Chapters 10 and 17; or Chapters 5, 6 and Part VI. Each of these would also provide a solid background for a follow-up course delving more deeply into one of many possible areas: algebraic number theory, algebraic topology, algebraic geometry, representation theory, Lie groups, etc.

The choice of new material and the style for developing and integrating it into the text are in consonance with a basic theme in the book: the power and beauty that accrues from a rich interplay between different areas of mathematics. The emphasis throughout has been to motivate the introduction and development of important algebraic concepts using as many examples as possible. We have not attempted to be encyclopedic, but have tried to touch on many of the central themes in elementary algebra in a manner suggesting the very natural development of these ideas.

A number of important ideas and results appear in the exercises. This is not because they are not significant, rather because they did not fit easily into the flow of the text but were too important to leave out entirely. Sequences of exercises on one topic are prefaced with some remarks and are structured so that they may be read without actually doing the exercises. In some instances, new material is introduced first in the exercises—often a few sections before it appears in the text—so that students may obtain an easier introduction to it by doing these exercises (e.g., Lagrange’s Theorem appears in the exercises in Section 1.7 and in the text in Section 3.2). All the exercises are within the scope of the text and hints are given [in brackets] where we felt they were needed. Exercises we felt might be less straightforward are usually phrased so as to provide the answer to the exercise; as well many exercises have been broken down into a sequence of more routine exercises in order to make them more accessible.

We have also purposely minimized the functorial language in the text in order to keep the presentation as elementary as possible. We have refrained from providing specific references for additional reading when there are many fine choices readily available. Also, while we have endeavored to include as many fundamental topics as possible, we apologize if for reasons of space or personal taste we have neglected any of the reader’s particular favorites.

We are deeply grateful to and would like here to thank the many students and colleagues around the world who, over more than 15 years, have offered valuable comments, insights and encouragement—their continuing support and interest have motivated our writing of this third edition.

David Dummit
Richard Foote
June, 2003