Mathematical Surveys and Monographs

Volume 94

Invariant Theory of Finite Groups

Mara D. Neusel Larry Smith



American Mathematical Society

Editorial Board

Peter Landweber Michael Loss, Chair Tudor Ratiu J. T. Stafford

2000 Mathematics Subject Classification. Primary 13A50, 55S10.

ABSTRACT. This book gives a comprehensive overview of the invariant theory of finite groups acting linearly on polynomial algebras. It spans the gamut from the classical methods and results of Emmy Noether, T. Molien, D. Hilbert and L. E. Dickson to the modern methods and insights obtained from using Steenrod algebra technology, as in the proof of the Landweber-Stong conjecture. Numerous examples illustrate the theory and techniques introduced.

Library of Congress Cataloging-in-Publication Data

Neusel, Mara D., 1964-

Invariant theory of finite groups / Mara D. Neusel, Larry Smith.

p. cm. — (Mathematical surveys and monographs, ISSN 0076-5376; v. 94)

Includes bibliographical references and index.

ISBN 0-8218-2916-5 (alk. paper)

1. Finite groups. 2. Invariants. I. Smith, L. (Larry), 1942– II. Title. III. Mathematical surveys and monographs; no. 94.

QA177.N46 2001 512'.2—dc21

2001053841

AMS softcover ISBN 978-0-8218-4981-1

Copying and reprinting. Individual readers of this publication, and nonprofit libraries acting for them, are permitted to make fair use of the material, such as to copy a chapter for use in teaching or research. Permission is granted to quote brief passages from this publication in reviews, provided the customary acknowledgment of the source is given.

Republication, systematic copying, or multiple reproduction of any material in this publication is permitted only under license from the American Mathematical Society. Requests for such permission should be addressed to the Assistant to the Publisher, American Mathematical Society, P.O. Box 6248, Providence, Rhode Island 02940-6248. Requests can also be made by e-mail to reprint-permission@ams.org.

> © 2002 American Mathematical Society. Reprinted by the American Mathematical Society, 2010. Typeset by *LS*T_EX.

Printed in the United States of America.

Solution The paper used in this book is acid-free and falls within the guidelines established to ensure permanence and durability. Visit the AMS home page at URL: http://www.ams.org/

10 9 8 7 6 5 4 3 2 1 15 14 13 12 11 10

Contents

1.	Invariants, their Relatives, and Problems	1
	1.1 Polynomial Invariants of Linear Groups	2
	1.2 Coinvariants and Stable Invariants	8
	1.3 Basic Problems in Invariant Theory	12
	1.4 Problems for Finite Groups	15
	1.5 Problems for Finite Groups over Finite Fields	20
	1.6 Problems for Special Representations	23
	1.7 What Makes Rings of Invariants Special?	25
2.	Algebraic Finiteness	29
	2.1 Emmy Noether's Finiteness Theorem	30
	2.2 The Transfer Homomorphism	33
	2.3 Emmy Noether's Bound	36
	2.4 Feshbach's Transfer Theorem	40
3.	Combinatorial Finiteness	45
	3.1 Molien's Theorem on Poincaré Series	46
	3.2 Poincaré Series of Permutation Representations	57
	3.3 The Hilbert-Serre Theorem on Poincaré Series	66
	3.4 Göbel's Theorem on Permutation Invariants	69
4.	Noetherian Finiteness	77
	4.1 Orbit Chern Classes	78
	4.2 A Refinement of Orbit Chern Classes	85
	4.3 Dade Bases and Systems of Parameters	99
	4.4 Euler Classes and Related Constructions	103
	4.5 The Degree Theorem	105

5. Homological Finiteness	113
5.1 The Koszul Complex	114
5.2 Hilbert's Syzygy Theorem	118
5.4 Poincará Duality Algebras	120
5.5 The Cohen-Macaulay Property	124
5.6 Homological and Cohomological Dimensions	137
5.7 The Gorenstein and Other Homological Properties	143
5.8 Examples	147
6 Modular Invariant Theory	151
6.1 The Dickson Algebra	152
6.2 Transvection Groups	156
6.3 p-Groups in Characteristic p	160
6.4 The Transfer Variety	168
6.5 The Koszul Complex and Invariant Theory	173
7. Special Classes of Invariants	185
7.1 Pseudoreflections and Pseudoreflection Groups	186
7.2 Coinvariants of Pseudoreflection Groups	194
7.3 Solvable, Nilpotent and Alternating Groups	203
7.4 GL(2, \mathbb{F}_p) and Some of Its Subgroups	212
7.5 Integer Representations of Finite Groups	221
8. The Steenrod Algebra and Invariant Theory	227
8.1 The Steenrod Operations	228
8.2 The Steenrod Algebra	231
8.3 The Hopf Algebra Structure of the Steenrod Algebra	236
8.5 The Landweber-Stong Conjecture	241
8.6 The Steenrod Algebra and the Dickson Algebra	255
	255
9. Invariant Ideals	259
9.2 The Invariant Prime Ideal Spectrum	260
9.3 Applications to the Transfer	275
9.4 Applications to Homological Properties	278
10 Lannes's T-Functor and Applications	283
10.1 The T-Functor and Invariant Theory	284
10.2 The T-Functor and Noetherian Finiteness	290
10.3 Change of Rings for Components	294
10.4 The T-Functor and Freeness	298
10.5 The T-Functor and Complete Intersections	303

10.6 Invariants of Stabilizer Subgroups10.7 A Last Look at the Transfer	 	307 310
Appendix A. Review of Commutative Algebra A.1 Gradings		315 315
A.2 Primary Decompositions and Integral Extensions		320
A.3 Noetherian Algebras		323
A.4 Graded Algebras and Modules	• • • • • •	327
References		331
Typography		357
Notation		359
Index		363