

Lectures on Matrices

J. H. M. Wedderburn



American Mathematical Society

Colloquium Publications

Volume 17

Lectures on Matrices

J. H. M. Wedderburn



American Mathematical Society
Providence, Rhode Island

2000 *Mathematics Subject Classification*. Primary 15-02.

Library of Congress Cataloging-in-Publication Data

Wedderburn, J. H. M. (Joseph Henry Maclagan), 1882–1948.

Lectures on matrices, by J. H. M. Wedderburn.

p. cm. — (American Mathematical Society Colloquium publications, ISSN 0065-9258 ; v. 17)
New York, American mathematical society, 1934.

“This book contains lectures on matrices given at Princeton University at various times since 1926.”—Pref.

Includes bibliography.

ISBN 978-0-8218-4610-0 (alk. paper)

1. Matrices. I. Title. II. Colloquium publications (American Mathematical Society) ; v. 17.

QA1.A5225 vol. 17a
512.8

35004487

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 Acquisitions Department, American Mathematical Society, 201 Charles Street, Providence, Rhode Island 02904-2294, USA. Requests can also be made by e-mail to reprint-permission@ams.org.

Reprinted by the American Mathematical Society, 1960, 2008

Printed in the United States of America.

∞ 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 <http://www.ams.org/>

10 9 8 7 6 5 4 3 13 12 11 10 09 08

PREFACE

This book contains lectures on matrices given at Princeton University at various times since 1920. It was my intention to include full notes on the history of the subject, but this has proved impossible owing to circumstances beyond my control, and I have had to content myself with very brief notes (see Appendix I). A bibliography is given in Appendix II. In compiling it, especially for the period of the last twenty-five years, there was considerable difficulty in deciding whether to include certain papers which, if they had occurred earlier, would probably have found a place there. In the main, I have not included articles which do not use matrices as an algebraic calculus, or whose interest lies in some other part of mathematics rather than in the theory of matrices; but consistency in this has probably not been attained.

Since these lectures have been prepared over a somewhat lengthy period of time, they owe much to the criticism of many friends. In particular, Professor A. A. Albert and Dr. J. L. Dorroh read most of the MS making many suggestions, and the former gave material help in the preparation of the later sections of Chapter X.

J. H. M. WEDDERBURN.

*Princeton, N. J.,
July 20, 1934.*

This page intentionally left blank

CONTENTS

PREFACE	PAGE iii
---------------	-------------

CHAPTER I

MATRICES AND VECTORS

SECTION

1. Linear transformations and vectors.....	1
2. Linear dependence.....	2
3. Linear vector functions and matrices.....	3
4. Scalar matrices.....	5
5. Powers of a matrix; adjoint matrices.....	6
6. The transverse of a matrix.....	8
7. Bilinear forms.....	9
8. Change of basis.....	9
9. Reciprocal and orthogonal bases.....	11
10. The rank of a matrix.....	14
11. Linear dependence.....	16

CHAPTER II

ALGEBRAIC OPERATIONS WITH MATRICES. THE CHARACTERISTIC EQUATION

1. Identities.....	20
2. Matric polynomials in a scalar variable.....	20
3-4. The division transformation.....	21
5-6. The characteristic equation.....	23
7-8. Matrices with distinct roots.....	25
9-12. Matrices with multiple roots.....	27
13. The square root of a matrix.....	30
14. Reducible matrices.....	31

CHAPTER III

INVARIANT FACTORS AND ELEMENTARY DIVISORS

1. Elementary transformations.....	33
2. The normal form of a matrix.....	34
3. Determinantal and invariant factors.....	36
4. Non-singular linear polynomials.....	37
5. Elementary divisors.....	38
6-7. Matrices with given elementary divisors.....	39
8-9. Invariant vectors.....	43

CHAPTER IV

VECTOR POLYNOMIALS. SINGULAR MATRIC POLYNOMIALS

1. Vector polynomials.....	47
2. The degree invariants.....	48
3-4. Elementary sets.....	49
5. Linear elementary bases.....	52
6. Singular linear polynomials.....	55

CHAPTER V
COMPOUND MATRICES

	PAGE
1. Compound matrices.....	63
2. The scalar product.....	63
3. Compound matrices.....	64
4. Roots of compound matrices.....	67
5. Bordered determinants.....	67
6-7. The reduction of bilinear forms.....	68
8. Invariant factors.....	71
9. Vector products.....	72
10. The direct product.....	74
11. Induced or power matrices.....	75
12-14. Associated matrices.....	76
15. Transformable systems.....	79
16-17. Transformable linear sets.....	80
18-19. Irreducible transformable sets.....	85

CHAPTER VI
SYMMETRIC, SKEW, AND HERMITIAN MATRICES

1. Hermitian matrices.....	88
2. The invariant vectors of a hermitian matrix.....	90
3. Unitary and orthogonal matrices.....	91
4. Hermitian and quasi-hermitian forms.....	92
5. Reduction of a quasi-hermitian form to the sum of squares.....	93
6. The Kronecker method of reduction.....	96
7. Cogredient transformation.....	98
8. Real representation of a hermitian matrix.....	100

CHAPTER VII
COMMUTATIVE MATRICES

1. Commutative matrices.....	102
2. Commutative sets of matrices.....	105
3. Rational methods.....	106
4. The direct product.....	108
5. Functions of commutative matrices.....	110
6. Sylvester's identities.....	111
7. Similar matrices.....	113

CHAPTER VIII
FUNCTIONS OF MATRICES

1. Matric polynomials.....	115
2. Infinite series.....	115
3. The canonical form of a function.....	116
4. Roots of 0 and 1.....	118
5-6. The equation $y^m = x$; algebraic functions.....	119
7. The exponential and logarithmic functions.....	122
8. The canonical form of a matrix in a given field.....	123
9. The absolute value of a matrix.....	125
10. Infinite products.....	127
11. The absolute value of a tensor.....	127
12. Matric functions of a scalar variable.....	128

CONTENTS

vii

	PAGE
13. Functions of a variable vector.....	130
14. Functions of a variable matrix.....	135
15-16. Differentiation formulae.....	136

CHAPTER IX

THE AUTOMORPHIC TRANSFORMATION OF A BILINEAR FORM

1. Automorphic transformation.....	140
2-3. The equation $y' = \pm aya^{-1}$	141
4. Principal idempotent and nilpotent elements.....	142
5. The exponential solution.....	144
6. Matrices which admit a given transformation.....	145

CHAPTER X

LINEAR ASSOCIATIVE ALGEBRAS

1. Fields and algebras.....	147
2. Algebras which have a finite basis.....	148
3. The matric representation of an algebra.....	149
4. The calculus of complexes.....	150
5. The direct sum and product.....	151
6. Invariant subalgebras.....	152
7. Idempotent elements.....	154
8-9. Matric subalgebras.....	156
10-12. The classification of algebras.....	158
13. Semi-invariant subalgebras.....	163
14. The representation of a semi-simple algebra.....	165
15. Group algebras.....	167

APPENDIX I

Notes.....	169
------------	-----

APPENDIX II

Bibliography.....	172
Index to bibliography.....	194
INDEX.....	197

This page intentionally left blank

CORRIGENDA

- page 4, line 9 from top: on second Σ read j for p
- page 6, Theorem 1, add: *and conversely, if a matrix is commutative with every other matrix, it is a scalar matrix.*
- page 7, line 12 from foot; for first and third A read $|A|$
- page 11, lines 10, 11 from foot: for $(Q'Q)$ read $(Q'Q)^{-1}$
- page 13, line 9 from foot: for $Sg_i x$ read $S\bar{g}_i x$
- page 13, line 6 from foot: for \bar{g}_{s+1} read \bar{g}'_{s+1}
- page 14, line 3 from top: before $a_j e_j$ read Σ .
- page 18, line 8 from foot: for j read γ_j
- page 20, line 8 from foot: for $r + 1$ read $r - 1$
- page 30, line 13 from top: for $=$ read $-$
- page 31, line 4 from foot: for second x_i read $x e_i$; add $e_1 + e_2 = 1$
- page 42, equation (16): for 1 read -1
- page 54, line 14 from foot; for (12) read (13)
- page 54, line 6 from foot: for (14) read (15)
- page 54, line 3 from foot: for (15) read (16)
- page 54, line 2 from foot: for (13) read (14)
- page 56, line 12 from top: correct term after Σ to read $k_{i, \theta+j} z_i$
- page 67, lines 4, 5, 6, 7: the exponent n on the second last C should read $\binom{n}{r}$.
- page 68, line 11 from foot: before Σ read $(-1)^r$
- page 68, line 8 from foot: before $|X|$ read $(-1)^r$
- page 74, line 11 from foot: for $r = 1$ read $r = 3$
- page 81, line 4 from foot: for $1/\beta_1!$ read $\beta_1!$ with similar change in last line
- page 84, line 13 from foot: interchange i and j .
- page 85, line 8 from foot: for \mathfrak{F}_1 read $\bar{\mathfrak{F}}_1$
- page 86, line 7 from top: for first e_1 read e_i

page 92, line 11 from foot: delete from "and if" to end of paragraph
 page 101, line 6 from foot: after hermitian insert $A = A'$
 page 103, line 4 from foot: delete first 0; for $q = t + 1$ read $q = s + 1$
 page 112, equation (23): for $\{ \}$ read $[]$
 page 116, line 7 from top: add Every power series converges when x is nilpotent.
 page 119, line 9 from top: for "at least . . . first" read "the H.C.F. of the t 's
 is relatively prime to m "
 page 122, line 4 from foot: multiply bracket by ϵ^{μ_i} and delete same inside
 page 122, equation (30): for g_{ij} read $p_{ij} = \epsilon^{-\mu_i} g_{ij}$
 page 123, lines 2 and 3 from top: for g_{ij} read p_{ij}
 page 123, equations (32) and (33): for π read 2π
 page 125, line 4 from top: read $\alpha_1^{r_1}(\lambda), \alpha_2^{r_2}(\lambda), \dots, \alpha_k^{r_k}(\lambda)$
 page 126, line 13 from top: for $| |$ read $| |$
 page 126, equation (45): for first α read a
 page 129, equation (63): in first term the bars should be heavy
 page 129, line 5 from foot: for $|x|$ read $|x|$
 page 134, line 6 from top: multiply right side of equation by 2
 page 136, line 10 from top: for ξ_r read ξ_{r-1}
 page 137, equation (103): read $\dot{p} = -\partial_q \mathfrak{D}$
 page 144, equation (24): read $x'axa^{-1}$
 page 156, line 6 from top: for second = read \leq and add " $\leq A$, whence $A = \Sigma A_{ij}$ "
 page 164, line 8 from top: for primitive read minimal
 page 164, line 7 from foot: for invariant read semi-invariant
 page 164, last line: before "complete" insert "suitably chosen"
 page 166, line 10 from foot: for equivalent read invariant
 page 166, line 5 from foot: for first B_2 read B_1
 page 167, Theorem 9: for $j \neq k$ read $i \neq t$
 page 171, line 5 from top: delete 80

APPENDIX I

NOTES¹

CHAPTER I

The calculus of matrices was first used in 1853 by Hamilton (1, p. 559ff, 480ff) under the name of "Linear and vector functions." Cayley used the term *matrix* in 1854, but merely for a scheme of coefficients, and not in connection with a calculus. In 1858 (2) he developed the basic notions of the algebra of matrices without recognizing the relation of his work to that of Hamilton; in some cases (e.g., the theory of the characteristic equation) Cayley gave merely a verification, whereas Hamilton had already used methods in three and four dimensions which extend immediately to any number of dimensions. The algebra of matrices was rediscovered by Laguerre (9) in 1867, and by Frobenius (18) in 1878.

1.03 Matric units seem to have been first used by B. Peirce (17); see also Grassmann (5, §381).

1.10 For the history of the notion of rank and nullity see Muir, *Theory of Determinants*, London 1906-1930; the most important paper is by Frobenius (290).

CHAPTER II

2.01-03 The principle of substitution given in §2.01 was understood by most of the early writers, but was first clearly stated by Frobenius, who was also the first to use the division transformation freely (20, p. 203).

2.04 The remainder theorem is implicit in Hamilton's proof of the characteristic equation; see also Frobenius (280).

2.05-12 The characteristic equation was proved by general methods for $n = 3, 4$ by Hamilton (1, p. 567; 8, p. 484ff; cf. also 4, 6). The first general statement was given by Cayley (2); the first general proof by Frobenius (18). See also the work of Frobenius cited below and 9, 10, 39, 41, 56, 59.

Hamilton, Cayley and other writers were aware that a matrix might satisfy an equation of lower degree than n , but the theory of the reduced equation seems to be due entirely to Frobenius (18, 140).

The theory of invariant vectors was foreshadowed by Hamilton, but the general case was first handled by Grassmann (5).

2.10 See Sylvester (42, 44) and Taber (96); see also 252.

2.13 The square root of a matrix was considered by Cayley (3, 12), Frobenius (139) and many others.

CHAPTER III

3.01 The idea of an elementary transformation seems to be due in the main to Grassmann (5).

¹ In these Notes, numbers refer to the Bibliography unless otherwise indicated.

3.02-07 The theory of pairs of bilinear forms, which is equivalent to that of linear polynomials, was first given in satisfactory form by Weierstrass (see Muth, 175) although the importance of some of the invariants had been previously recognized by Sylvester. The theory in its matrix form is principally due to Frobenius (18, 20).

The theory of matrices with integral elements was first investigated by Smith (see Muth, 175) but was first given in satisfactory form by Frobenius (20). The form given in the text is essentially that of Kronecker (92).

3.04 The proof of Theorem 3 is a slight modification of that of Frobenius (20).

3.08 Invariant vectors were discussed by Hamilton (1, 8) and other writers on quaternions and vector analysis. The earliest satisfactory account seems to be that of Grassmann (5).

CHAPTER IV

The developments of this chapter are, in the main, a translation of Kronecker's work (see Muth, 175, p. 93ff). See also de Séguier (259).

CHAPTER V

5.03 From the point of view of matrix theory, the principal references are Schur (198), Rados (105, 106), Stephanos (185), and Hurwitz (117). See Loewy (284, p. 138) for additional references; also Muir, *Theory of Determinants*, London 1906-1930.

5.09 Non-commutative determinants were first considered by Cayley (Phil. Mag. 26 (1845), 141-145); see also Joly (195) and Sylvester (43).

5.10-11 See Loewy (284, p. 149); also 176, 178, 185, 198.

5.12 The principal references are Schur (198) and Weyl (440, chap. 5).

CHAPTER VI

For general references see Loewy (284, pp. 118-137), also Muth (175), Hilton (314, chap. 6, 8) and Muir, *Theory of Determinants*, London 1906-1930.

6.01 The method of proving that the roots are real is essentially that of Tait (10, chap. 5); see also 36, 60, 228, 399.

6.03 See Loewy (284, pp. 130-137), Baker (215) and Frobenius (292). See also 7, 18, 99, 113, 114, 115, 124, 135, 139, 210, 221, 273, 302, 307, 320, 371, 400, 414, 466, 476.

6.04 See Dickson (392).

6.05 See Loewy (284, pp. 128-135).

6.07 For references see Muth (175, p. 125) and Frobenius (139).

CHAPTER VII

7.10-02 See Cayley (2), Frobenius (18), Bucheim (59), Taber (98, 112), and Hilton (314, chap. 5); also 83, 86, 98, 137, 184, 197, 209, 223, 242, 250, 264, 301, 382.

7.03 See Frobenius (280).

7.05 See Frobenius (140); also 350.

7.06-07 See Sylvester (42, 44) and Taber (96); see also 252.

CHAPTER VIII

8.01-03 See Sylvester (36), Bucheim (59, 69); also 134, 371.

8.02,07 See Hamilton (1, p. 545ff; 8, §316), Grassmann (5, §454), Laguerre (9). Many writers define the exponential and trigonometric functions and consider the question of convergence, e.g., 79, 80, 103, 389, 449; also in connection with differential equations, 13, 133, 258.

8.04-05 Roots of 0 and 1 have been considered by a large number of writers; see particularly the suite of papers by Sylvester in 1882-84; also 18, 67, 76, 107, 242, 255, 264, 277, 279, 381, 411, 430, 474, 539.

8.08 See 20, 94, 246, 256, 257, 274, 303, 338, 399.

8.09-11 The absolute value of a matrix was first considered by Peano (75) in a somewhat different form from that given here; see also 273, 348, 389, 472, 473, 494. For infinite products see 133, 324, 326, 389, 494.

8.12 In addition to the references already given above, see 10, 16, 18, 187, 418, 419, and also many writers on differential equations.

CHAPTER IX

The problem of the automorphic transformation in matrices was first considered by Cayley (3, 7) who, following a method used by Hermite, gave the solution for symmetric and skew matrices; his solution was put in simpler form by Frobenius (18). Cayley failed to impose necessary conditions in the general case which was first solved by Voss (85, 108, 162, 163). The properties of the principal elements were given by Taber (125, 134; see also 127, 149, 156, 158, 231). Other references will be found in Loewy (284, pp. 130-137); see also 9, 19, 153, 154, 161, 167, 168, 169, 187, 229, 371.

APPENDIX II

BIBLIOGRAPHY

1853

1. HAMILTON, W. R.: Lectures on quaternions, p. 480ff. Dublin.

1858

2. CAYLEY, A.: A memoir on the theory of matrices, (1857). Lond. Phil. Trans. 148, 17-37; Coll. Works 2, 475-496.
3. CAYLEY, A.: A memoir on the automorphic transformation of a bipartite quadric function, (1857). Lond. Phil. Trans. 148, 39-46; Coll. Works 2, 497-505.

1862

4. HAMILTON, W. R.: On the existence of a symbolic and biquadratic equation which is satisfied by the symbol of linear or distributive operation on a quaternion. Phil. Mag. (4) 24, 127-128.
5. GRASSMANN, H.: Ausdehnungslehre, p. 241ff. Berlin; Werke 1, Teil 2, p. 240.

1864

6. HAMILTON, W. R.: On the existence of a symbolic and biquadratic equation ..., (1862). Proc. Roy. Irish Acad. 8, 190-191.

1866

7. CAYLEY, A.: A supplementary memoir on the theory of matrices, (1865). Lond. Phil. Trans. 156, 25-35; Coll. Works 5, 438-448.
8. HAMILTON, W. R.: Elements of quaternions, §347ff. London. 2nd ed. 1 (1899), 2 (1901); German translation, 2 vols. (Glan), 1881-1901.

1867

9. LAGUERRE, E. N.: Sur le calcul des systèmes linéaires. Journ. Ec. Polyt. 42, 215-264; Oeuvres 1, 221-267.
10. TAIT, P. G.: An elementary treatise on quaternions, chap. V. Oxford. 2nd ed., Cambridge 1873; 3d ed., Cambridge 1890; German translation (Schreff) 1890; French translation (Plarr) 1882-1884.

1869

11. TAIT, P. G.: Note on the reality of the roots of the symbolical cubic ..., (1867). Proc. Roy. Soc. Edinb. 6, 92-93; Sci. Papers 1, 74-75.

1872

12. CAYLEY, A.: On the extraction of the square root of a matrix of the third order. Proc. Roy. Soc. Edinb. 7, 675-682.
13. TAIT, P. G.: Note on linear differential equations in quaternions, (1870). Proc. Roy. Soc. Edinb. 7, 311-318; Sci. Papers 1, 153-158.
14. TAIT, P. G.: Mathematical notes, (1871). Proc. Roy. Soc. Edinb. 7, 498-499.
15. TAIT, P. G.: Note on the strain function. Proc. Roy. Soc. Edinb. 7, 667-668; Sci. Papers 1, 194-198.

1873

16. TAIT, P. G.: Introduction to quaternions, chap. X (with P. Kelland). London. 2nd ed. 1882; 3d ed. 1904.

1875

17. PEIRCE, B.: On the uses and transformations of linear algebra. Proc. Amer. Acad. Boston (2) 10, 395-400; reprinted, Amer. Journ. Math. 4 (1881), 216-221.

1878

18. FROBENIUS, G.: Über lineare Substitutionen und bilineare Formen, (1877). Crelle 84, 1-63.

1879

19. FROBENIUS, G.: Über die schiefe Invariante einer bilinearen oder quadratischen Form, (1878). Crelle 86, 44-71.
 20. FROBENIUS, G.: Theorie der linearen Formen mit ganzen Koeffizienten, (1878). Crelle 86, 146-208.
 21. PLARR, G.: On the solution of the equation $V_{\rho\rho\rho} = 0 \dots$, (1876). Trans. Roy. Soc. Edinb. 28, 45-91.

1880

22. CAYLEY, A.: On the transformation of coordinates. Proc. Cambr. Phil. Soc. 3, 178-184; Coll. Works 11, 136-142.
 23. CAYLEY, A.: On the matrix $\begin{pmatrix} a & b \\ c & d \end{pmatrix}$ and in connection therewith the function $\frac{ax+b}{cx+d}$. Mess. of Math. 9, 104-109; Coll. Works 11, 252-257.
 24. FROBENIUS, G.: Theorie der linearen Formen mit ganzen Koeffizienten, (1879). Crelle 88, 96-116.
 25. FROBENIUS, G.: Zur Theorie der Transformation der Thetafunktionen, (1879). Crelle, 89, 40-46.

1881

26. LAISANT, C.-A.: Introduction à la méthode des quaternions, chap. 10. Paris.

1882

27. CLIFFORD, W. K.: A fragment on matrices, (1875). Math. Papers, 337-341.
 28. PEIRCE, C. S.: On the relative form of quaternions. Johns Hopkins Circ. 1, 179.
 29. PLARR, G.: On a particular case of the symbolic cubic, (1881). Proc. Roy. Soc. Edinb. 11, 342-354.
 30. SYLVESTER, J. J.: Sur les puissances et les racines de substitutions linéaires. Comptes Rendus 94, 55-59; Math. Papers, 3, 562-564.
 31. SYLVESTER, J. J.: Sur les racines des matrices unitaires. Comptes Rendus 94, 396-399; Math. Papers 3, 565-567.
 32. SYLVESTER, J. J.: On the properties of a split matrix. Johns Hopkins Circ. 1, 210-211; Math. Papers 3, 645-646.
 33. SYLVESTER, J. J.: A word on nonions. Johns Hopkins Circ. 1, 241-242; Math. Papers 3, 647-650.

1883

34. PEIRCE, C. S.: On a class of multiple algebras, (1882). Johns Hopkins Univ. Circ. 2, 3-4.
 35. PEIRCE, C. S.: (Correspondence). Johns Hopkins Univ. Circ. 2, 86-88.

36. SYLVESTER, J. J.: On the equation to the secular inequalities in the planetary theory. *Phil. Mag.* (5) 16, 267-269.
37. SYLVESTER, J. J.: On the involution of two matrices of the second order. *Brit. Assoc. Report 1883*, 430-432; *Math. Papers 4*, 115-117.
38. SYLVESTER, J. J.: Sur les quantités formant un groupe de nonions analogues aux quaternions de Hamilton. *Comptes Rendus 97*, 1336-1340; *Math. Papers 4*, 118-121.

1884

39. BUCHEIM, A.: Mathematical notes. *Mess. of Math.* 13, 62-66.
40. BUCHEIM, A.: Proof of Professor Sylvester's "Third law of motion." *Phil. Mag.* (5) 18, 459-460.
41. FORSYTH, A. R.: Proof of a theorem by Cayley in regard to matrices. *Mess. of Math.* 13, 139-142.
42. SYLVESTER, J. J.: On quaternions, nonions, sedenions etc. *Johns Hopkins Circ.* 3, 7-9; *Math. Papers 4*, 122-132.
43. SYLVESTER, J. J.: On involutants and other allied species of invariants to matrix systems. *Johns Hopkins Circ.* 3, 9-18, 34-35; *Math. Papers 4*, 133-145.
44. SYLVESTER, J. J.: On the three laws of motion in the world of universal algebra. *Johns Hopkins Circ.* 3, 33-34, 57; *Math. Papers 4*, 146-151.
45. SYLVESTER, J. J.: Equations in matrices. *Johns Hopkins Circ.* 3, 122; *Math. Papers 4*, 152-153.
46. SYLVESTER, J. J.: Sur les quantités formant un groupe de nonions analogues aux quaternions de Hamilton. *Comptes Rendus 98*, 273-276, 471-475; *Math. Papers 4*, 154-159.
47. SYLVESTER, J. J.: Sur la solution d'une classe très étendue d'équations en quaternions. *Comptes Rendus 98*, 651-652; *Math. Papers 4*, 162.
48. SYLVESTER, J. J.: Sur une extension de la loi de Harriot relative aux équations algébriques. *Comptes Rendus 98*, 1026-1030; *Math. Papers 4*, 169-172.
49. SYLVESTER, J. J.: Sur les équations monothétiques. *Comptes Rendus 99*, 13-15; *Math. Papers 4*, 173-175.
50. SYLVESTER, J. J.: Sur l'équation en matrices $px = xq$. *Comptes Rendus 99*, 67-71, 115-116; *Math. Papers 4*, 176-180.
51. SYLVESTER, J. J.: Sur la solution du cas le plus général des équations linéaires en quantités binaires *Comptes Rendus 99*, 117-118; *Math. Papers 4*, 181-182.
52. SYLVESTER, J. J.: Sur les deux méthodes, celle de Hamilton et celle de l'auteur pour résoudre l'équation linéaire en quaternions. *Comptes Rendus 99*, 473-476, 502-505; *Math. Papers 4*, 183-187.
53. SYLVESTER, J. J.: Sur la solution explicite de l'équation quadratique de Hamilton en quaternions ou en matrices du second ordre. *Comptes Rendus 99*, 555-558, 621-631; *Math. Papers 4*, 188-198.
54. SYLVESTER, J. J.: Sur la résolution générale de l'équation linéaire en matrices d'un ordre quelconque. *Comptes Rendus 99*, 409-412; 432-436; *Math. Papers 4*, 199-205.
55. SYLVESTER, J. J.: Sur l'équation linéaire trinôme en matrices d'un ordre quelconque. *Comptes Rendus 99*, 527-529; *Math. Papers 4*, 206-207.
56. SYLVESTER, J. J.: Lectures on the principles of universal algebra. *Amer. Journ. Math.* 6, 270-286; *Math. Papers 4*, 208-224.
57. SYLVESTER, J. J.: On the solution of a class of equations in quaternions. *Phil. Mag.* (5) 17, 392-397; *Math. Papers 4*, 225-230.
58. SYLVESTER, J. J.: On Hamilton's quadratic equation and the general unilateral equation in matrices. *Phil. Mag.* (5) 18, 454-458; *Math. Papers 4*, 231-235.

1885

59. BUCHEIM, A.: On the theory of matrices, (1884). Proc. Lond. Math. Soc. 16, 63-82.
 60. BUCHEIM, A.: On a theorem relating to symmetrical determinants, (1884). Mess. of Math. 14, 143-144.
 61. BUCHEIM, A.: A theorem on matrices. Mess. of Math. 14, 167-168.
 62. CAYLEY, A.: On the quaternion equation $qQ - Qq' = 0$. Mess. of Math. 14, 108-112; Coll. Works 12, 300-304.
 63. CAYLEY, A.: On the matricial equation $qQ - Qq' = 0$. Mess. of Math. 14, 176-178; Coll. Works 12, 311-313.
 64. MUIR, T.: New relations between bipartite functions and determinants with a proof of Cayley's theorem in matrices. Proc. Lond. Math. Soc. 16, 276-286.
 65. SYLVESTER, J. J.: On the trinomial unilateral quadratic equation in matrices of the second order. Quart. Journ. Math. 20, 305-312; Math. Papers 4, 272-277.
 66. WEYR, E.: O základní větě v theorii matric, (1884). Sitzb. K. Böhm. Ges. d. Wissens. 1884, 148-152.
 67. WEYR, E.: Sur la théorie des matrices. Comptes Rendus 100, 787-789.
 68. WEYR, E.: Repartition des matrices en espèces et formation de toutes les espèces. Comptes Rendus 100, 966-969.

1886

69. BUCHEIM, A.: An extension of a theorem of Professor Sylvester's relating to matrices. Phil. Mag. (5) 22, 173-174.
 70. CAYLEY, A.: On the transformation of the double theta functions. Quart. Journ. Math. 21, 142-178; Coll. Works 12, 358-389.
 71. KUMAMOTO, A.: Matrices no theory ni tsuite shirusu. Tokyo Sugaku Butsurigaku Kwai Kizi, 3, 153-161.

1887

72. BUCHEIM, A.: On double algebra, (1886). Mess. of Math. 16, 62-63.
 73. BUCHEIM, A.: Note on triple algebra, (1886). Mess. of Math. 16, 111-114.
 74. GIBBS, J. W.: Multiple algebra, (1886). Proc. Amer. Assoc. Adv. Sci. 35, 37-66.
 75. PEANO, G.: Integrazione per serie delle equazioni differenziali lineari. Atti R. Accad. Torino, 22, 437-446. Translated under title "Intégration par séries des équations différentielles linéaires." Math. Ann. 32 (1888), 450-456.

1888

76. BRUNEL, G.: Sur les racines des matrices zéroïdales. Comptes Rendus 106, 467-470.
 77. BUCHEIM, A.: On a theorem of Prof. Klein's relating to symmetric matrices, (1887). Mess. of Math. 17, 79.
 78. MORRICE, G.: Multiplication of nonions, (1887). Mess. of Math. 17, 104-105.
 79. WEYR, E.: O binárných matricích, (1887). Sitzb. K. Böhm. Ges. d. Wissens. 1887, 358-400.
 80. WEYR, E.: Sur la réalisation des systèmes associatifs de quantités complexes à l'aide des matrices, (1887). Sitzb. K. Böhm. Ges. d. Wissens. 1887, 616-618.

1889

81. BUCHEIM, A.: Note on matrices in involution, (1887). Mess. of Math. 18, 102-104.
 82. SYLVESTER, J. J.: Sur la réduction biorthogonale d'une forme linéolaire à sa forme canonique. Comptes Rendus 108, 651-653; Math. Papers 4, 638-640.
 83. WEYR, E.: O theorii form bilineárných. Praze. Translated under title "Zur Theorie der bilinearen Formen" Monatsh. f. Math. u. Phys. 1 (1890); 163-236.

1890

84. TABER, H.: On the theory of matrices. Amer. Journ. Math. 12, 337-396.
 85. VOSS, A.: Über die conjugirte Transformation einer bilinearen Form in sich selbst, (1889). Münch. Ber. 19, 175-211.
 86. VOSS, A.: Über die mit einer bilinearen Form vertauschbaren Formen, (1889). Münch. Ber. 19, 283-300.
 87. VAN WETTUM, T. B.: De quaternion van Hamilton als matrix van Cayley. Nieuw Archief 17, 206-216.

1891

88. CARVALLO, E.: Sur les systèmes linéaires, Monatsh. f. Math. u. Phys. 2, 177-216, 225-266, 311-330.
 89. CAYLEY, A.: Note on the involutant of two binary matrices. Mess. of Math. 20, 136-137; Coll. Works 13, 74-75.
 90. CAYLEY, A.: Note on a theorem in matrices. Proc. Lond. Math. Soc. 22, 458; Coll. Works 13, 114.
 91. CHAPMAN, C. H. On the matrix which represents a vector. Amer. Journ. Math. 13, 363-380.
 92. KRONECKER, L.: Reduction der Systeme mit n^2 ganzzahligen Elementen. Crelle 107, 135-136.
 93. MOLENBROEK, P.: Theorie der Quaternionen. Leiden.
 94. RADOS, G.: Zur Theorie der adjungirte Substitutionen. Math. és Term. Értesitö 1891; Math. Ann. 48 (1897), 417-424.
 95. STUDY, E.: Recurrierende Reihen und bilineare Formen, (1889). Monatsh. f. Math. u. Phys. 2, 23-54.
 96. TABER, H.: On certain identities in the theory of matrices, (1890). Amer. Journ. Math. 13, 159-172.
 97. TABER, H.: On the application to matrices of any order of the quaternion symbols S and V , (1890). Proc. Lond. Math. Soc. 22, 67-79.
 98. TABER, H.: On the matricial equation $\varphi\Omega = \Omega\varphi$. Proc. Amer. Acad. Boston 26, 64-66.
 99. TABER, H.: On certain properties of symmetric, skew symmetric, and orthogonal matrices. Proc. Lond. Math. Soc. 22, 449-469.
 100. VAN WETTUM, T. B.: Over den quaternion-matrix. Nieuw Archief 18, 168-186.

1892

101. VAN ELFRINKHOF, L.: De oplossing van lineaire vector-verglijkingen in bijzondere gevallen. Nieuw Archief 19, 132-142.
 102. VAN ELFRINKHOF, L.: Opmerkingen naar aanleiding der verhandelingen over quaternion-matrices van den heer Th. B. van Wettum. Nieuw Archief 19, 143-150.
 103. METZLER, W. H.: On the roots of matrices. Amer. Journ. Math. 14, 326-377.
 104. MOLIEN, T.: Über Systeme höherer complexer Zahlen, (1891). Diss. Dorpat; Math. Ann. 41, 83-156.
 105. RADOS, G.: Zur Theorie der orthogonalen Substitutionen, (1891). Math. és Term. Értesitö 10, 16-18; Math. Natur. Ber. aus Ungarn 10 (1893), 95-97.
 106. RADOS, G.: Die Theorie der adjungirten Substitutionen, (1891). Math. és Term. Értesitö 10, 34-42; Math. Natur. Ber. aus Ungarn 10 (1893), 98-107.
 107. ROST, G.: Untersuchungen über die allgemeinste lineare Substitution, deren Potenzen eine endliche Gruppe bilden. Diss. Würzburg; Leipzig.
 108. VOSS, A.: Über die cogredienten Transformationen einer bilinearen Form in sich selbst, (1890). Münch. Abh. 17, 235-356.

1893

109. ÉLIE, B.: La fonction vectorielle et ses applications à la physique. *Mém. Soc. des Sci. Phys. et Natur. Bordeaux* (4) 3, 1-137.
110. MCAULAY, A.: Utility of quaternions in physics. London.
111. METZLER, W. H.: On certain properties of symmetric, skew symmetric, and orthogonal matrices, (1892). *Amer. Journ. Math.* 15, 274-282.
112. TABER, H.: On a theorem of Sylvester's relating to non-degenerate matrices. *Proc. Amer. Acad. Boston* 27, 46-55.
113. TABER, H.: Note on the representation of orthogonal matrices, (1892). *Proc. Amer. Acad. Boston* 27, 163-164.
114. TABER, H.: On real orthogonal substitution. *Proc. Amer. Acad. Boston* 28, 212-217.
115. TABER, H.: On the linear transformations between two quadrics. *Proc. Lond. Math. Soc.* 24, 290-306.

1894

116. FRANKLIN, F.: Note on induced linear substitutions. *Amer. Journ. Math.* 16, 205-206.
117. HURWITZ, A.: Zur Invariantentheorie. *Math. Ann.* 45, 381-404.
118. METZLER, W. H.: Matrices which represent vectors. *Boston Tech. Quart.* 6 (1893), 348-351.
119. METZLER, W. H.: Compound determinants, (1893). *Amer. Journ. Math.* 16, 131-150.
120. METZLER, W. H.: Homogeneous strains. *Annals of Math.* 8, 148-156.
121. PEANO, G.: Sur les systèmes linéaires. *Monatsh. f. Math. u. Phys.* 5, 136.
122. SFORZA, G.: Sulle forme bilineari simili. *Giorn. Mat.* 32, 293-316; 33 (1895), 80-105; 34 (1896), 252-278.
123. TABER, H.: On orthogonal substitutions that can be expressed as a function of a single alternate (or skew symmetric) linear substitution, (1893). *Amer. Journ. Math.* 16, 123-130.
124. TABER, H.: On orthogonal substitutions. *Bull. New York Math. Soc.* 3, 251-259.
125. TABER, H.: On the automorphic linear transformation of a bilinear form. *Proc. Amer. Acad. Boston* 29, 178-179.
126. TABER, H.: On the group of automorphic linear transformations of a bilinear form. *Proc. Amer. Acad. Boston* 29, 371-381.
127. VAN WETTUM, T. B.: *Researches on matrices and quaternions.* Leyden.

1895

128. BRILL, J.: On the application of the theory of matrices to the discussion of linear differential equations with constant coefficients, (1894). *Proc. Cambr. Phil. Soc.* (3) 8, 201-210.
129. VAN ELFRINKHOF, L.: Der vergelijking $V_{\rho\varphi\rho} = 0$. *Nieuw Archief* (2) 1, 76-87.
130. VAN ELFRINKHOF, L.: Draaiings-matrices en quaternions. *Nieuw Archief* (2) 1, 88-100.
131. HENSEL, K.: Über die Elementartheiler componirter Systeme, (1894). *Crelle* 114, 109-115.
132. JOLY, C. J.: The theory of linear vector functions, (1894). *Trans. Roy. Irish Acad.* 30, pt. 16, 597-647.
133. SCHLESINGER, L.: *Handbuch der Theorie der linearen Differentialgleichungen*, p. 91 ff. Leipzig.
134. TABER, H.: On the automorphic linear transformation of an alternate bilinear form. *Math. Ann.* 46, 561-583.
135. TABER, H.: On those orthogonal substitutions that can be generated by the repetition of an infinitesimal orthogonal substitution. *Proc. Lond. Math. Soc.* 26, 364-376.
136. VAN WETTUM, T. B.: Over het quotient van twee ruimte-vectoren, en over een quaternion. *Nieuw Archief* (2) 1, 68-75.

1896

37. BRILL, J.: Note on matrices, (1895). Proc. Lond. Math. Soc. 27, 35-38.
38. FROBENIUS, G.: Zur Theorie der Scharen bilinearer Formen, (1881). Zürich Naturf. Ges. 41, T. 2, 20-23.
39. FROBENIUS, G.: Über die cogredienten Transformation der bilinearen Formen. Berlin Sitzb. 1896, 7-16.
140. FROBENIUS, G.: Über vertauschbare Matrizen. Berlin Sitzb. 1896, 601-614.
141. JOLY, C. J.: Scalar invariants of two linear vector functions, (1895). Trans. Roy. Irish Acad. 30 pt. 18, 709-728.
142. JOLY, C. J.: Quaternion invariants of linear vector functions and quaternion determinants. Proc. Roy. Irish Acad. (3) 4 pt. 1, 1-15.
143. LANDSBERG, G.: Über Fundamentalsysteme und bilineare Formen, (1895). Crelle 116, 331-349.
144. LAURENT, H.: Exposé d'une théorie nouvelle des substitutions linéaires. Nouv. Ann. (3) 15, 345-365.
145. PINCHERLE, S.: Le operazioni distributive e le omografie. Rend. R. Ist. Lomb. (2) 29, 397-405.
146. RADOS, G.: Adjungirte quadratische Formen. Math. és Term. Értesítő 14, 26-32; Math. Natur. Ber. aus Ungarn 14 (1898), 85-91.
147. RADOS, G.: Zur Theorie der adjungirten bilinearen Formen. Math. és Term. Értesítő 14, 165-175; Math. Natur. Ber. aus Ungarn 14 (1898), 116-127.
148. TABER, H.: On orthogonal substitution, (1893). Math. Papers, Intern. Congr. Chicago, 395-400.
149. TABER, H.: Note on the automorphic linear transformation of a bilinear form, (1895). Proc. Amer. Acad. Boston 31, 181-192.

1897

150. BAKER, H. F.: Abelian functions, App. II. Cambridge.
151. BRILL, J.: Supplementary note on matrices, (1896). Proc. Lond. Math. Soc. 28, 368-370.
152. LAURENT, H.: Applications de la théorie des substitutions linéaires à l'étude des groupes. Nouv. Ann. (3) 16, 149-168.
153. LOEWY, A.: Bemerkung zur Theorie der konjugirten Transformation einer bilinearen Form in sich selbst, (1896). Münch. Ber. 26, 25-30.
154. LOEWY, A.: Zur Theorie der linearen Substitutionen. Math. Ann. 48, 97-110.
155. SHAW, J. B.: The linear vector operator of quaternions, (1895). Amer. Journ. Math. 19, 267-282.
156. TABER, H.: On the transformations between two symmetric or alternate bilinear forms. Math. Review 1, 120-126.
157. TABER, H.: On the group of real linear transformations whose invariant is a real quadratic form, (1896). Math. Review 1, 154-168; Proc. Amer. Acad. Boston 32, 77-83.
158. TABER, H.: Notes on the theory of bilinear forms. Bull. Amer. Math. Soc. 3, 156-164.
159. TAIT, P. G.: On the linear and vector function, (1896). Proc. Roy. Soc. Edinb. 21, 160-164; Sci. Papers 2, 406-409.
160. TAIT, P. G.: On the linear and vector function. Proc. Roy. Soc. Edinb. 21, 310-312; Sci. Papers 2, 410-412.
161. TAIT, P. G.: Note on the solution of equations in linear and vector functions. Proc. Roy. Soc. Edinb. 21, 497-505; Sci. Papers 2, 413-420.
162. VOSS, A.: Über die Anzahl der cogredienten und adjungirten Transformationen einer bilinearen Form in sich selbst, (1896). Münch. Ber. 26, 211-272.
163. VOSS, A.: Symmetrische und alternirende Lösungen der Gleichung $\dot{S}X = XS'$, (1896). Münch. Ber. 26, 273-281.

1898

164. BACHMANN, P.: Zahlentheorie, vol. 4, p. 275 ff. Leipzig.
165. JOLY, C. J.: The associative algebra applicable to hyperspace, (1897). Proc. Roy. Irish Acad. (3) 5, 73-123.
166. LAURENT, H.: Exposé d'une théorie nouvelle des substitutions. Journ. de Math. (5) 4, 75-119.
167. LOEWY, A.: Über die bilineare Formen mit conjugirt imaginären Variablen, (1897). Nova Acta Leop-Carol. Acad. 71, 379-446.
168. LOEWY, A.: Über bilineare Formen mit conjugirt imaginären Variablen. Math. Ann. 50, 557-576.
169. MUIR, T.: A reinvestigation of the problem of the automorphic linear transformation of a bipartite quadric. Amer. Jour. Math. 20, 215-228.
170. RADOS, G.: Zur Theorie der adjungirten quadratischen Formen, (1897). Verh. Intern. Math. Congr. Zürich 1, 163-165.
171. RAVUT, L.: Remarques sur une matrice. Nouv. Ann. (3) 17, 118-120.
172. STEPHANOS, C.: Sur un mode de composition des déterminants et des formes bilinéaires. Giorn. Mat. 36, 376-379.
173. WHITEHEAD, A. N.: Universal algebra, vol. 1, pp. 248-269, 318-346. Cambridge.

1899

174. BAKER, H. F.: (Note on a paper of Prof. Burnside's). Proc. Lond. Math. Soc. 30, 195-198.
175. MUTH, P.: Theorie und Anwendung der Elementartheiler. Leipzig.
176. RADOS, G.: Gruppen inducierter Substitutionen, (1898). Math. és Term. Értésítő 17, 44-65; Math. Natur. Ber. aus Ungarn 17 (1901), 227-247.
177. SHAW, J. B.: Some generalisations in multiple algebra and matrices. Bull. Amer. Math. Soc. 5, 381-382.
178. STEPHANOS, C.: Sur une extension du calcul des substitutions linéaires. Comptes Rendus 128, 593-596.
179. STUDY, E.: Theorie der gemeinen und höheren complexen Grössen. Encycl. der Math. Wiss. I 1, 413 ff.

1900

180. AMALDI, U.: Sulle sostituzioni lineari commutabili. Rend. R. Ist. Lomb. (2) 33, 731-744.
181. BENDIXSON, J.: Sur les racines d'une équation fondamentale. Öfv. K. Svenska Vet.-Akad. Förh. Stockholm 57, 1099-1103.
182. LOEWY, A.: Über Scharen reeller quadratischer und Hermitescher Formen. Crelle 122, 53-72.
183. LOEWY, A.: Über die Transformation einer Hermiteschen Form von nicht verschwindender Determinante in sich. Gött. Nachr. 1900, 298-302.
184. SCHELESINGER, L.: Über vertauschbare lineare Substitutionen. Crelle 121, 177-187.
185. STEPHANOS, C.: Sur une extension du calcul des substitutions linéaires. Journ. de Math. (5) 6, 73-128.
186. TAIT, P. G.: On the linear and vector function, (1899). Proc. Roy. Soc. Edinb. 22, 547-549; Sci. Papers 2, 424-426.

1901

187. BROMWICH, T. J. P.A.: Canonical reduction of linear substitutions and bilinear forms with a dynamical application, (1900). Proc. Lond. Math. Soc. 32, 79-118, 321-352.
188. BROMWICH, T. J. P.A.: Note on Weierstrass's reduction of a family of bilinear forms, (1900). Proc. Lond. Math. Soc. 32, 158-163.
189. BROMWICH, T. J. P.A.: On a canonical reduction of bilinear forms with special consideration of congruent reductions, (1900). Proc. Lond. Math. Soc. 32, 321-352.

190. BROMWICH, T. J. P.A.: Theorems on matrices and bilinear forms, (1900). Proc. Cambr. Phil. Soc. 11, 75-89.
191. BROMWICH, T. J. P.A.: Ignorance of coordinates as a problem in linear substitutions. Proc. Cambr. Phil. Soc. 11, 163-167.
192. BUCHEIM, A.: Review: "Theorie und Anwendung der Elementarteiler" by Dr. P. Muth. Bull. Amer. Math. Soc. 7, 308-316.
193. CARLINI, L.: Sul prodotto di due matrici rettangolari coniugate, (1900). Period. di Mat. (2) 3, 193-198.
194. GIBBS, J. W., AND E. B. WILSON: Vector analysis, chap. 5. New York.
195. JOLY, C. J.: Hamilton's "Elements of quaternions," 2nd ed., appendix. London.
196. LOEWY, A.: Über die Verallgemeinerung eines Weierstrassschen Satzes. Crelle 123, 258-262.
197. PLEMELJ, J.: Ein Satz über vertauschbare Matrizen und seine Anwendung in der Theorie linearer Differentialgleichungen. Monatsh. f. Math. u. Phys. 12, 82-96.
198. SCHUR, I.: Über eine Klasse von Matrizen die sich einer gegebenen Matrix zuordnen lassen. Diss. Berlin.

1902

199. AUTONNE, L.: Sur les groupes linéaires, réels, et orthogonaux. Bull. Soc. Math. France 30, 121-134.
200. AUTONNE, L.: Sur l'Hermitien, (1901). Rend. Circ. Mat. Palermo 16, 104-128.
201. BENDIXSON, J.: Sur les racines d'une équation fondamentale. Acta Math. 25, 359-365.
202. BURNSIDE, W.: On the characteristic equations of certain linear substitutions. Quart. Journ. Math. 33, 80-84.
203. CARLINI, L.: Sopra due tipi di relazioni . . . , (1901). Period. di Mat. (2) 4, 175-179.
204. DICKSON, L. E.: A matrix defined by the quaternion group. Amer. Math. Monthly 9, 243-248.
205. HENSEL, K., AND G. LANDSBERG: Theorie der algebraischen Funktionen einer Variablen, p. 174 ff. Leipzig.
206. HIRSCH, A.: Sur les racines d'une équation fondamentale. Acta Math. 25, 367-370.
207. NICCOLLETTI, O.: Sulle matrici associate ad una matrice data. Atti R. Accad. Torino 37, 655-659.
208. SCHUR, I.: Über einen Satz aus der Theorie der vertauschbaren Matrizen. Berlin Sitzb. 1902, 120-125.
209. VOLTERRA, V.: Sui fondamenti della teoria delle equazioni differenziali lineari. Mem. Soc. Ital. Sci. (3) 12, 3-68.

1903

210. AUTONNE, L.: Sur la décomposition d'une substitution linéaire, réelle et orthogonale, en un produit d'inversions. Comptes Rendus 136, 1185-1186.
211. AUTONNE, L.: Sur la canonisation des formes bilinéaires. Nouv. Ann. (4) 3, 57-64.
212. AUTONNE, L.: Sur l'hypohermitien. Bull. Soc. Math. France 31, 140-155.
213. AUTONNE, L.: Sur quelques propriétés des matrices hypohermitiennes. Bull. Soc. Math. France 31, 268-271.
214. AUTONNE, L.: Sur la décomposition d'une substitution linéaire, réelle et orthogonale, en un produit d'inversions. Ann. Univ. Lyon I, fasc. 12.
215. BAKER, H. F.: On some cases of matrices with linear invariant factors, (1902). Proc. Lond. Math. Soc. 35, 379-384.
216. BAKER, H. F.: On the invariant factors of a determinant. Proc. Cambr. Phil. Soc. 12, 65-77.
217. FROBENIUS, G.: Theorie der hypercomplexen Größen. Berlin Sitzb. 1903, 504-537, 634-645.

218. HUDSON, R. W. H. T.: Matrix notation in the theory of screws, (1902). *Mess. of Math.* 32, 51-57.
219. JOLY, C. J.: The multilinear quaternion function, (1902). *Proc. Roy. Irish Acad.* 24, 47-52.
220. JOLY, C. J.: Quaternions and projective geometry. *Trans. Roy. Soc. Lond.* 201, 223-327.
221. RADOS, G.: Notes sur les substitutions orthogonales. *Math. Natur. Ber. aus Ungarn* 18, 231-235.
222. RADOS, G.: Zur Theorie der algebraischen Resolventen. *Math. Natur. Ber. aus Ungarn* 18, 236-249.
223. SHAW, J. B.: Theory of linear associative algebra, (1902). *Trans. Amer. Math. Soc.* 4, 251-287.
224. WEDDERBURN, J. H. M.: On the applications of quaternions in the theory of differential equations. *Trans. Roy. Soc. Edinb.* 40, 709-721.
225. WELLSTEIN, J.: Über die Frobeniusschen Kovarianten einer Bilinearform, (1901). *Arch. der Math. u. Phys.* (3) 5, 229-241.

1904

226. BAKER, H. F.: Note on Sylvester's theorems on determinants. *Collected Math. Papers of J. J. Sylvester*, 1, 647-650.
227. BURNSIDE, W.: On linear substitutions of determinant unity with integral coefficients. *Mess. of Math.* 33, 133-137.
228. HENSEL, K.: Theorie der Körper von Matrizen. *Crelle* 127, 116-166.
229. LAURENT, H.: Sur les transformations qui transforment une forme du second degré donnée en une autre également donnée. *Nouv. Ann.* (4) 4, 29-38.
230. DE SÉQUIER, J. A.: Éléments de la théorie des groupes abstraits, p. 159 ff. Paris.
231. TABER, H.: On the real automorphic linear transformation of a real bilinear form, (1903). *Proc. Amer. Acad. Boston* 39, 307-320.
232. WEDDERBURN, J. H. M.: Note on the linear matrix equation. *Proc. Edinb. Math. Soc.* 22, 49-53

1905

233. BROMWICH, T. J. I'A.: On the roots of the characteristic equation of a linear substitution, (1904). *Brit. Assoc. Report* 1904, 440-441.
234. CUNNINGHAM, E.: On the normal series satisfying linear differential equations, (1904). *Phil. Trans. Roy. Soc. Lond.* 205, 1-35.
235. JOLY, C. J.: A manual of quaternions, chap. 8. London.
236. MUTH, P.: Über reelle Äquivalenz von Scharen reeller quadratischer Formen. *Crelle* 128, 302-321.
237. SCHLESINGER, L.: Beiträge zur Theorie der Systeme linearer homogener Differentialgleichungen. *Crelle* 128, 263-297.
238. SCHUR, I.: Zur Theorie der vertauschbaren Matrizen. *Crelle* 130, 66-76.

1906

239. AUTONNE, L.: Sur les polynomes à coefficients et à variable hypercomplexes. *Bull. Soc. Math. France* 34, 205-212.
240. BROMWICH, T. J. I'A.: On the roots of the characteristic equation of a linear substitution, (1904). *Acta Math.* 30, 297-304.
241. GIBBS, J. W.: Elements of vector analysis, chap. 3, (1884). *Sci. Papers* 2, 53 ff.
242. KREIS, H.: Contribution à la théorie des systèmes linéaires. Thèse, Zurich.
243. PETR, K.: Několik poznámek o determinantech. *Casopis pro Pest. Math. u. Fys.* 35, 311-321.

244. PETR, K.: Néhány megjegyzés a determinánsok elméletéhez. *Math. es Phys. Lapok* 15, 353-365; translated under title 'Einige Bemerkungen über die Determinanten.' *Math. Natur. Ber. aus Ungarn* 25 (1908), 95-105.
245. WEDDERBURN, J. H. M.: On a theorem in hypercomplex numbers. *Proc. Roy. Soc. Edinb.* 26, 48-50.

1907

246. WIRTH, J.: Über die Elementarteiler einer linearen homogenen Substitution. . Diss. Freiburg.
247. BÔCHER, M.: Introduction to higher algebra, chap. 8-13, 20-22. New York.
248. BRILL, J.: On the expression of the so-called biquaternions and triquaternions with the aid of quaternary matrices, (1906). *Proc. Lond. Math. Soc.* (2) 4, 124-130.
249. PERRON, O.: Zur Theorie der Matrices, (1906). *Math. Ann.* 64, 248-263.
250. DE SÉGUIER, J.-A.: Sur la théorie des matrices. *Comptes Rendus* 145, 1259-1260.
251. SHAW, J. B.: Synopsis of linear associative algebras. Washington, D. C.
252. WEDDERBURN, J. H. M.: On hypercomplex numbers. *Proc. Lond. Math. Soc.* (2) 6, 77-118

1908

253. CARTAN, E. AND E. STUDY.: Nombres complexes. *Encycl. des Sci. Math.* I 1, fasc. 3, 413 ff.
254. FROBENIUS, G.: Über Matrizen aus positiven Elementen. *Berlin Sitzb.* 1908, 471-476.
255. KREIS, H.: Auflösung der Gleichung $X^n = A$. *Zürich Naturf. Ges.* 53, 366-376.
256. NICOLETTI, O.: Sulla riduzione a forma canonica di una sostituzione lineare omogenea e di un fascio di forme bilineari. *Ann. di Mat.* (3) 14, 265-326.
257. RANUM, A.: Concerning linear substitutions of finite period with rational coefficients, (1907). *Trans. Amer. Math. Soc.* 9, 183-202.
258. SCHLESINGER, L.: Vorlesungen über lineare Differentialgleichungen. Leipzig.
259. DE SÉGUIER, J.: Sur la théorie des matrices. *Bull. Soc. Math. France* 36, 20-40.
260. DE SÉGUIER, J.: Sur les formes bilinéaires. *Comptes Rendus* 146, 1247-1248.
261. WILSON, E. B.: On the theory of double products and strains in hyperspace, (1907). *Connecticut Acad. Trans.* 14, 1-57.

1909

262. AUTONNE, L.: Sur les groupes de matrices linéaires non invertibles. *Ann. Univ. Lyon* I fasc. 25.
263. BALL, R.: Linear vector functions, (1908). *Brit. Assoc. Report* 1908, 611-612.
264. CECIONI, F.: Sulle equazioni fra matrici $AX = XB$, $X^n = A$. *R. Accad. dei Lincei Rend.* (5) 18, 566-571.
265. CECIONI, F.: Sulla caratteristica del prodotto di due matrici. *Period. di Mat.* (3) 6, 253-265.
266. DICKSON, L. E.: On commutative linear groups, (1907). *Quart. Journ. Math.* 40, 167-196.
267. FROBENIUS, G.: Matrizen aus positiven Elementen. II. *Berlin Sitzb.* 1909, 514-518.
268. GAMBERINI, G.: Una speciale classe di matrici quadrate permutabili, (1908). *Giorn. di Mat.* 47, 137-155.
269. GAMBERINI, G.: Alcuni risultati intorno al prodotto di due matrici quadrate d'ordine n . Rome.
270. GAMBERINI, G.: Sulle relazioni fra alcune forme del prodotto di due matrici quadrate d'ordine n . Rome.
271. JACKSON, D.: Resolution into involutory substitutions of the transformations of a non-singular bilinear form into itself. *Trans. Amer. Math. Soc.* 10, 479-484.

272. KARST, L.: Lineare Funktionen und Gleichungen. Prog. (127) Realprogymn. Lichtenberg bei Berlin.
273. SCHUR, I.: Über die charakteristischen Wurzeln einer linearen Substitution mit einer Anwendung auf die Theorie der Integralgleichungen. Math. Ann. 66, 488-510.
274. DE SÉGUIER, J. A.: Sur les formes bilinéaires et quadratiques. Journ. de Math. (6) 5, 1-63.
275. WELLSTEIN, J.: Die Dekomposition der Matrizen. Gött. Nachr. 1909, 77-99.
276. WELLSTEIN, J.: Kriterien für die Potenzen einer Determinante. Math. Ann. 67, 490-497.
277. WIDDER, W.: Untersuchungen über die allgemeinste lineare Substitution mit vorgegebener p^{ter} Potenz, (1908). Diss. Würzburg; Leipzig.

1910

278. AUTONNE, L.: Sur les matrices linéaires échangeables à une matrice donnée. Jour. Ec. Poly. (2) 14, 83-131.
279. CECIONI, F.: Sopra alcune operazioni algebriche sulle matrici, (1909). Ann. R. Scuola Norm. Sup. Pisa 11.
280. FROBENIUS, G.: Über die mit einer Matrix vertauschbaren Matrizen. Berlin Sitzb. 1910, 3-15.
281. HAWKES, H. E.: The reduction of families of bilinear forms, (1908). Amer. Journ. Math. 32, 101-114.
282. HUTCHINSON, J. I.: On linear transformations which leave an Hermitian form invariant, (1909). Amer. Journ. Math. 32, 195-206.
283. KREIS, H.: Einige Anwendungen der Matricestheorie. Progr. Gymn. Winterthur.
284. LOEWY, A.: Pascal's "Repertorium der höheren Analysis." Leipzig, 2 ed., chap. 2, 79-153.

1911

285. BURGESS, H. T.: The simultaneous reduction of a quadratic and a bilinear form by the same transformation on both x 's and y 's, (1910; abstract). Bull. Amer. Math. Soc. 17, 65-66.
286. BURGESS, H. T.: The application of matrices to cubic forms. (Abstract.) Bull. Amer. Math. Soc. 17, 299.
287. CHÂTELET, A.: Sur certains ensembles de tableaux et leur application à la théorie des nombres. Ann. Ec. Norm. (3) 28, 105-202.
288. DAVID, L.: (On matrices of algebraic iteration; in Magyar.) Math. és Term. Értesítő 29, 444-449.
289. ELIE, B.: Relations entre les paramètres Cayléens de trois substitutions orthogonales dont l'une est égale au produit des deux autres. Bull. des Sci. Math. (2) 35, 162-180.
290. FROBENIUS, G.: Über den Rang einer Matrix. Berlin Sitzb. 1911, 20-29, 128-129.
291. FROBENIUS, G.: Über den von L. Bieberbach gefundenen Beweis eines Satzes von C. Jordan. Berlin Sitzb. 1911, 241-248.
292. FROBENIUS, G.: Über unitäre Matrizen. Berlin Sitzb. 1911, 373-378.
293. RABINOVIC, J.: (Linear vector functions; in Russian.) Odessa.
294. RANUM, A.: The general term of a recurring series. Bull. Amer. Math. Soc. 17, 457-461.

1912

295. AMALDI, U.: Sulle sostituzioni lineari commutabili. Rend. R. Ist. Lomb. (2) 45, 433-445.
296. AUTONNE, L.: Sur une propriété des matrices linéaires. Nouv. Ann. (4) 12, 118-127.

297. DRACH, J., AND W. F. MEYER: Théorie des formes et des invariants. *Encycl. des Sci. Math.* I 2, fasc. 4, 440 ff.
298. FROBENIUS, G.: Über Matrizen aus nicht negativen Elementen. *Berlin. Sitzb.* 1912, 456-477.
299. HILTON, H.: On properties of certain linear homogeneous substitutions, (1911) *Proc. Lond. Math. Soc.* (2) 10, 273-283.
300. HILTON, H.: On cyclant substitutions, (1911). *Mess. of Math.* 41, 49-51.
301. HILTON, H.: Substitutions permutable with a canonical substitution, (1911). *Mess. of Math.* 41, 110-118.
302. HILTON, H.: On symmetric and orthogonal substitutions. *Mess. of Math.* 41, 146-154.
303. LATTÈS, S.: Sur la réduction des substitutions linéaires. *Comptes Rendus* 155, 1482-1484.

1913

304. AUTONNE, L.: Sur les matrices hypohermittiennes et les unitaires. *Comptes Rendus* 156, 858-860.
305. BIRKHOFF, G. D.: A theorem on matrices of analytic functions. *Math. Ann.* 74, 122-133.
306. CULLIS, C. E.: *Matrices and determinoids*, vol. 1. Cambridge.
307. HILTON, H.: Some properties of symmetric and orthogonal substitutions, (1912). *Proc. Lond. Math. Soc.* (2) 12, 94-99.
308. LOEWY, A.: Über lineare homogene Differentialsysteme und ihre Sequenzen. *Sitzb. Heidl. Akad.* 1913, A17.
309. WEDDERBURN, J. H. M.: Note on the rank of a symmetrical matrix. *Annals of Math.* (2) 15, 29.

1914

310. BLISS, G. A.: A note on symmetric matrices. *Annals of Math.* (2) 15, 43-44.
311. CIPOLLA, M.: Le sostituzioni ortogonali non-cayleyane, (1913). *Atti Accad. Gioenia, Catania* (5) 7, mem. 2, 1-18.
312. DICKSON, L. E.: *Linear algebras*, chap. 1. Cambridge.
313. HILTON, H.: Properties of certain homogeneous linear substitutions. *Annals of Math.* (2) 15, 195-201.
314. HILTON, H.: *Homogeneous linear substitutions*. Oxford.
315. METZLER, W. H.: On the rank of a matrix, (1913). *Annals of Math.* (2) 15, 161-165.
316. STEIN, J.: Beiträge zur Matrizenrechnung mit Anwendung auf die Relativitätstheorie. Tübingen.
317. WEDDERBURN, J. H. M.: On continued fractions in non-commutative quantities. *Annals of Math.* (2) 15, 101-105.
318. WEDDERBURN, J. H. M.: Note on the rank of a symmetrical matrix. II. *Annals of Math.* (2) 16, 86-88.

1915

319. AMATO, V.: Sulla forma canonica delle sostituzioni ortogonali periodiche. *Atti Accad. Gioenia, Catania* (5) 8, mem. 15, 1-8.
320. AUTONNE, L.: Sur les matrices hypohermittiennes et sur les matrices unitaires. *Ann. Univ. Lyon* I fasc. 38.
321. BOEHM, K.: Über einen Determinantensatz, in welchem das Multiplikationstheorem als besonderer Fall enthalten ist. *Crelle* 145, 250-253.
322. KRAWCZUK, M.: (On groups of permutable matrices; in Russian.) *Soc. Math. Khar-koff* (2) 14, 163-176.
323. LATTÈS, S.: Sur les multiplicités linéaires invariantes par une substitution linéaire donnée. *Comptes Rendus* 160, 671-674.

324. PERRON, O.: Über konvergente Matrixprodukte. Sitzb. Heidl. Akad. 6, A4, 1-27.
 325. WEDDERBURN, J. H. M.: On matrices whose coefficients are functions of a single variable. Trans. Amer. Math. Soc. 16, 328-332.

1916

326. BIRKHOFF, G. D.: Infinite products of analytic matrices. Trans. Amer. Math. Soc. 17, 386-404.
 327. BURGESS, H. T.: A practical method of determining elementary divisors. Annals of Math. 18, 4-6.
 328. BURGESS, H. T.: On the matrix equation $BX = C$. Amer. Math. Monthly 23, 152-155.
 329. CULLIS, C. E.: Primitive matrices and the primitive degrees of a matrix. Bull. Calcutta Math. Soc. 6, 35-54.
 330. LATTÈS, S.: Sur une forme canonique des substitutions linéaires. Ann. Toulouse (3) 6, 1-84.
 331. LEVI, B.: Introduzione alla analisi matematica. Paris.
 332. SCORZA, G.: Intorno alla teoria generale delle matrici di Riemann e ad alcune sue applicazioni. Rend. Circ. Mat. Palermo 41, 263-379.
 333. TABER, H.: Conditions for the complete reducibility of groups of linear substitutions. Amer. Journ. Math. 38, 337-372.
 334. WHITTAKER, E. T.: On the theory of continued fractions. Proc. Roy. Soc. Edinb. 36, 243-255.
 335. WIDDER, W.: Über orthogonale, involutorische und orthogonal-involutorische Substitutionen. Progr. K. Alten Gymn. Würzburg.

1917

336. CULLIS, C. E.: Primitive matrices and the primitive degrees of a matrix. Pt. II. Bull. Calcutta Math. Soc. 8, 1-32.
 337. KOWALEWSKI, G.: Natürliche Normalform linearer Transformationen. Leipz. Ber. 69, 325-335.
 338. LOEWY, A.: Die Begleitmatrix eines linearen homogenen Differentialausdruckes. Gött. Nachr. 1917, 255-263.
 339. SZÁSZ, O.: Über eine Verallgemeinerung des Hadamardschen Determinantensatzes. Monatsh. f. Math. u. Phys. 28, 253-257.

1918

340. BURGESS, H. T.: Solution of the matrix equation $X^{-1}AX = N$. Annals of Math. 19, 30-36.
 341. CULLIS, C. E.: Matrices and determinoids, vol. 2. Cambridge.
 342. LOEWY, A.: Über Matrizen- und Differentialkomplexe, (1915-17). Math. Ann. 78, 1-51, 343-358, 359-368.
 343. LOEWY, A.: Über einen Fundamentalsatz für Matrizen oder lineare homogene Differentialsysteme. Sitzb. Heidl. Akad. 1918, A5, 1-36.
 344. MOORE, C. L. E., AND H. B. PHILLIPS: The dyadics which occur in a point-space of three dimensions. Proc. Amer. Acad. Boston 53, 387-438.
 345. MUIR, T.: Note on the construction of an orthogonant. Proc. Roy. Soc. Edinb. 38, 146-153.
 346. SCORZA, G.: Sopra alcune notevoli matrici riemanniane. Atti R. Accad. Sci. Torino 53, 598-607.
 347. STUDY, E.: Zur Theorie der linearen Gleichungen. Acta Math. 42, 1-61.
 348. TOEPLITZ, O.: Das algebraische Analogon zu einem Satz von Fejer. Math. Zeits. 2, 187-197.

1919

349. BENNETT, A. A.: Products of skew symmetric matrices. *Bull. Amer. Math. Soc.* 25, 455-458.
 350. PHILLIPS, H. B.: Functions of matrices. *Amer. Journ. Math.* 41, 266-278.
 351. SPEISER, A.: Zahlentheoretische Sätze aus der Gruppentheorie. *Math. Zeit.* 5, 1-6.

1920

352. BOSE, A. C.: Review: Cullis's Matrices and Determinoids. *Bull. Calcutta Math. Soc.* 10, 243-256; 11, 51-82.
 353. COOLIDGE, J. L.: The geometry of Hermitian forms, (1918). *Trans. Amer. Math. Soc.* 21, 44-51.
 354. GHOSH, N.: Potent divisors of the characteristic matrix of a minimum simple square anti-slope. *Bull. Calcutta Math. Soc.* 11, 1-6.
 355. LEVEUGLE, R.: Précis de calcul géométrique, chap. 9. Paris.
 356. LOEWY, A.: Begleitmatrizen und lineare homogene Differentialausdrücke, (1919). *Math. Zeitschr.* 7, 58-125.
 357. PIDDUCK, F. B.: Functions of limiting matrices. *Proc. Lond. Math. Soc.* (2) 19, 398-408.

1921

358. CULLIS, C. E.: Evaluation of the product matrix in a commutantal product of simple matrices having given nullities, (1920). *Bull. Calcutta Math. Soc.* 11, 105-150.
 359. KRULL, W.: Über Begleitmatrizen und Elementarteilerttheorie. *Diss. Freiburg.*
 360. SCORZA, G.: Alcune proprietà delle algebre regolari. *Note e Memorie di Mat.* 1, 198-209.
 361. SCORZA, G.: Le algebre di ordine qualunque e le matrici di Riemann. *Rend. Circ. Mat. Palermo* 45, 1-204.
 362. SCORZA, G.: Corpi numerici e algebre. *Messina.*
 363. SZÁSZ, O.: Über Hermitesche Formen mit rekurrirender Determinante und über rationale Polynome, (1920). *Math. Zeits.* 11, 24-57.

1922

364. DAHR, S.: On the inverse of an undegenerate non-plural quadrature slope, (1921). *Bull. Calcutta Math. Soc.* 12, 85-92.
 365. HITCHCOCK, F. L.: A solution of the linear matrix equation by double multiplication. *Proc. Amer. Nat. Acad. Sci.* 8, 78-83.
 366. LOGSDON, M. I.: Equivalence and reduction of pairs of Hermitian forms, (1921). *Amer. Journ. Math.* 44, 247-260.
 367. RADON, J.: Lineare Scharen orthogonaler Matrizen, (1921). *Hamburg Abh.* 1, 1-14.
 368. SCHUR, I.: Über Ringbereiche im Gebiete der ganzzahligen linearen Substitutionen. *Berlin Sitzb.* 1922, 145-168.
 369. SHAW, J. B.: *Vector calculus*, chap. 9. New York.
 370. VELEN, O., AND P. FRANKLIN. On matrices whose elements are integers, (1921). *Annals of Math.* (2) 23, 1-15.
 371. WEDDERBURN, J. H. M.: The automorphic transformation of a bilinear form, (1921). *Annals of Math.* 23, 122-134.

1923

372. BIRKHOFF, G. D., AND R. E. LANGER.: The boundary problems and developments associated with a system of ordinary linear differential equations of the first order. *Proc. Amer. Acad. Boston* 58, 51-128.
 373. BRAHANA, H. R.: A theorem concerning certain unit matrices with integer elements. *Annals of Math.* 24, 265-270.

374. DICKSON, L. E.: Algebras and their arithmetics. Chicago.
 375. HASSE, H.: Symmetrische Matrizen im Körper der rationalen Zahlen. *Crelle* 153, 12-43.
 376. HITCHCOCK, F. L.: On double polyadics, with application to the linear matrix equation. *Proc. Amer. Acad. Boston*, 58, 353-395.
 377. MEHMKE, R.: Einige Sätze über Matrizen, (1922). *Crelle* 152, 33-39.
 378. WEINSTEIN, A.: Fundamentalsatz der Tensorrechnung, (1922). *Math. Zeitschr.* 16, 78-91.
 379. WELTZIEN, C.: Die n -te Wurzel aus einer homogenen linearen Substitution von 3 Veränderlichen. *Sitzb. Berl. Math. Ges.* 22, 48.

1924

380. DICKSON, L. E.: Algebras and their arithmetics. *Bull. Amer. Math. Soc.* 30, 247-257.
 381. KRAVČUK, M. (Quadratic forms and linear transformations; in Ukrainian.) *Mem. Kiev Acad. Sci.* 1.
 382. KRAVČUK, M.: (On the theory of commutative matrices; in Ukrainian.) *Bull. Kiev Acad. Sci.* 1, 28-33.
 383. KÜRSCHÁK, J.: On matrices connected with Sylvester's dialytic eliminant. *Trans. Roy. Soc. So. Africa* 11, 257-261.
 384. MUIR, T.: Note on a property of bigradient arrays connected with Sylvester's dialytic eliminant. *Trans. Roy. Soc. So. Africa*, 11, 101-104.

1925

385. BORN, M., AND P. JORDAN. *Zur Quantenmechanik. Zeitschr. f. Phys.* 34, 858-888.
 386. CULLIS, C. E.: *Matrices and determinoids*, vol. 3, pt. 1. Cambridge.
 387. KÜRSCHÁK, J.: *Speciális Mátrixokról. Math. és Phys. Lapok* 32, 9-13.
 388. SCHUR, I.: Einige Bemerkungen zur Determinantentheorie. *Sitzb. Akad. Berlin* 1925, 454-463.
 389. WEDDERBURN, J. H. M.: The absolute value of the product of two matrices. *Bull. Amer. Math. Soc.* 31, 304-308.

1926

390. BECK, H.: *Einführung in die Axiomatik der Algebra.* Berlin.
 391. BORN, M., W. HEISENBERG AND P. JORDAN: *Zur Quantenmechanik. II*, (1925). *Zeitschr. f. Phys.* 53, 557-615.
 392. DICKSON, L. E.: *Modern algebraic theories.* New York.
 393. DUBNOV, J. S.: (Redoubled symmetric orthogonal matrices; in Russian.) *Moscow State Univ. Ins. Math. Mech.* 1926, 33-54.
 394. HENSEL, K.: Über Potenzenreihen von Matrizen. *Crelle* 155, 107-110.
 395. KAGAN, V. F.: (On some number-systems following from the Lorentz transformation; in Russian.) *Moscow State Univ. Inst. Math. Mech.* 1926, 3-31.
 396. KRULL, W.: *Theorie und Anwendung der verallgemeinerten Abelschen Gruppen.* *Sitzb. Heidl. Akad.* 1926, 1.
 397. MACDUFFEE, C. C.: The nullity of a matrix relative to a field, (1925). *Annals of Math.* 27, 133-139.
 398. RILEY, J. L.: Theory of matrices over any division algebra. *Bull. Calcutta Math. Soc.* 17, 1-12.
 399. WEDDERBURN, J. H. M.: Note on matrices in a given field. *Annals of Math.* 27, 245-248.

1927

400. ARAMATA, K.: Über einen Satz für unitäre Matrizen. *Tôhoku Math. Journ.* 28, 281.
 401. DICKSON, L. E.: *Algebren und ihre Zahlentheorie.* Zürich.

402. FISCHER, E.: Über die Cayleysche Eliminationsmethode, (1926). *Math. Zeitschr.* 26, 497-550.
403. FRISCH, R.: Sur le théorème des déterminants de M. Hadamard. *Comptes Rendus* 185, 1244-1245.
404. KRAWTCHOUK, M.: Über vertauschbare Matrizen. *Rend. Circ. Mat. Palermo* 51, 126-130.
405. VON NEUMANN, J.: Zur Theorie der Darstellungen kontinuierlicher Gruppen. *Berlin Sitzb.* 1927, 76-90.
406. PORCU-TORTRINI, E.: Sulle potenze delle matrici di secondo ordine. *Atti Pontificia Accad.* 80, 150-153.
407. PORCU-TORTRINI, E.: Calcolo delle potenze delle matrici di secondo ordine mediante riduzione alla forma canonica. *Atti Pontificia Accad.* 80, 277-281.
408. PORCU-TORTRINI, E.: Terzo procedimento del calcolo delle potenze delle matrici di second' ordine. *Atti Pontificia Accad.* 80, 348-353.
409. SCHUR, I.: Über die rationalen Darstellungen der allgemeinen linearen Gruppe. *Berlin Sitzb.* 1927, 58-75.
410. SPAMPINATO, N.: Nuovi contributi alla teoria generale delle matrici di Riemann. *Rend. Circ. Mat. Palermo* 51, 238-258.
411. TURNBULL, H. W.: The matrix square and cube roots of unity. *Journ. Lond. Math. Soc.* 2, 242-244.

1928

412. AITKEN, A. C.: On the latent roots of certain matrices, (1927). *Proc. Edinb. Math. Soc.* (2) 1, 135-138.
413. AITKEN, A. C.: Note on the elementary divisors of some related matrices. *Proc. Edinb. Math. Soc.* (2) 1, 166-168.
414. BRAUER, R.: Über einen Satz für unitäre Matrizen. *Tôhoku Math. Journ.* 30, 72.
415. BROWNE, E. T.: Involutions that belong to a linear class. *Annals of Math.* 29, 483-492.
416. BURGATTI, P.: Sulle equazioni algebriche a matrice. *Boll. Un. Mat. Ital.* 7, 65-69.
417. DICKSON, L. E.: A new theory of linear transformations and pairs of bilinear forms, (1924). *Proc. Intern. Congr. Math. Toronto*, 1, 361-363.
418. FANTAPPIÈ, L.: Le calcul des matrices. *Comptes Rendus* 186, 619-621.
419. GIORGI, G.: Sulle funzioni delle matrici. *R. Accad. Lincei Rend.* (6) 7, 178-184.
420. GIORGI, G.: Nuove osservazioni sulle funzioni delle matrici. *R. Accad. Lincei Rend.* (6) 8, 3-8.
421. HENSEL, K.: Über den Zusammenhang zwischen den Systemen und ihren Determinanten. *Crelle* 159, 246-254.
422. KOWALEWSKI, G.: Über lineare Differentialsysteme mit konstanten Koeffizienten. *Leipz. Ber.* 80, 359-366.
423. MACDUFFEE, C. C.: A correspondence between matrices and quadratic ideals, (1927). *Annals of Math.* 29, 199-214.
424. MARTIS, S.: Ricerca di un'espressione razionale per le potenze di una matrice di secondo ordine. *R. Accad. Lincei Rend.* (6) 8, 130-133.
425. MARTIS, S.: Sugli esponenziali delle matrici di secondo ordine e loro applicazione alla teoria dei gruppi. *R. Accad. Lincei Rend.* (6) 8, 276-280.
426. MARTIS, S.: Calcolo del logaritmo di una matrice di secondo ordine, *R. Accad. Lincei Rend.* (6) 8, 474-480.
427. ORY, H.: Sur l'équation $x^n = a$ ou a est un tableau carré du deuxième ordre. *Comptes Rendus* 187, 1012-1014.
428. POLYA, G.: Über die Funktionalgleichung der Exponentialfunktionen im Matrizenkalkül. *Berlin Sitzb.* 1928, 96-99.

429. PORCU-TORTRINI, E.: Calcolo delle funzioni qualunque di matrici di second' ordine. R. Accad. Lincei Rend. (6) 7, 206-208.
430. ROTH, W. E.: A solution of the matrix equation $P(X) = A$, (1927). Trans. Amer. Math. Soc. 30, 579-596.
431. SCHRUKTA, L.: Ein Beweis des Hauptsatzes der Theorie der Matrizes, (1924). Monatsh. f. Math. u. Phys. 35, 83-86.
432. TOSCANO, L.: Determinanti involutori, (1927). Rend. R. Ist. Lombardo (2) 61, 187-195.
433. TOSCANO, L.: Equazioni reciproche a matrice. R. Accad. Lincei Rend. (6) 8, 664-669.
434. TURNBULL, H. W.: The theory of determinants, matrices, and invariants. London.
435. TURNBULL, H. W.: Non-commutative algebra, (1927). Math. Gaz. 14, 12-22.
436. TURNBULL, H. W.: On differentiating a matrix, (1927). Proc. Edinb. Math. Soc. (2) 1, 111-128.
437. VAIDYANATHASWAMY, R.: Integer roots of the unit matrix. Journ. Lond. Math. Soc. 3, 121-124.
438. VAIDYANATHASWAMY, R.: On the possible periods of integer-matrices. Journ. Lond. Math. Soc. 3, 268-272.
439. VOGHERA, G.: Sulla forma canonica delle matrici, (1927). Boll. Un. Mat. Ital. 7, 32-34.
440. WEYL, H.: Gruppentheorie und Quantenmechanik. Leipzig.

1929

441. BECKENBACH, E. F.: An inequality for definite hermitian determinants. Bull. Amer. Math. Soc. 35, 325-329.
442. CHERUBINO, S.: Un'applicazione del calcolo di matrici alla teoria delle forme quadratiche. Rend. R. Ist. Lomb. (2) 62, 505-514.
443. CHERUBINO, S.: Alcune osservazioni sulle matrici rettangolari e loro utilità per la decomposizione di una forma quadratica in somme di quadrati. Rend. R. Ist. Lomb. (2) 62, 623-649.
444. MACDUFFEE, C. C.: An introduction to the theory of ideals in linear associative algebras, (1927). Trans. Amer. Math. Soc. 31, 71-90.
445. MACDUFFEE, C. C.: On the independence of the first and second matrices of an algebra. Bull. Amer. Math. Soc. 35, 344-349.
446. MARTIS, S.: Ricerca di un'espressione razionale per le potenze di una matrice del terz'ordine. R. Accad. Lincei Rend. (6) 9, 206-213.
447. PILLAI, S. S.: A theorem concerning the primitive periods of integer matrices. Journ. Lond. Math. Soc. 4, 250-251.
448. ROTH, W. E.: A convenient check on the accuracy of the product of two matrices. Amer. Math. Monthly 36, 37-38.
449. SCHLESINGER, L.: Über den Logarithmus einer Matrix. Crelle 161, 199-200.
450. SCORZA, G.: Sulle matrici di Riemann. R. Accad. Lincei Rend. (6) 9, 253-258.
451. SHODA, K.: Über die mit einer Matrix vertauschbaren Matrizen. Math. Zeits. 29, 696-712.
452. TOSCANO, L.: Equazioni a matrice con radici reali. Tôhoku Math. Journ. 32, 27-31.
453. TSUJI, M.: On the roots of the characteristic equation of a certain matrix. Proc. Imp. Acad. Tokyo 5, 111-112.
454. WINTNER, A.: Spektraltheorie der unendlichen Matrizen. Leipzig.

1930

455. ALBERT, A. A.: The non-existence of pure Riemann matrices with normal multiplication algebras of order sixteen, (1929). Annals of Math. 31, 375-380
456. ALBERT, A. A.: On the structure of pure Riemann matrices with non-commutative multiplication algebras. Proc. Amer. Nat. Acad. Sci. 16, 308-312.

457. ALBERT, A. A.: On direct products, cyclic division algebras, and pure Riemann matrices. *Proc. Amer. Nat. Acad. Sci.* 16, 313-315.
458. AMANTE, S.: Risoluzione, nel campo delle matrici complesse, di una qualsiasi equazione analitica a coefficienti numerici. *R. Accad. Lincei Rend.* (6) 12, 290-296.
459. BELL, E. T.: A type of commutative matrices. *Bull. Calcutta Math. Soc.* 22, 53-60.
460. BORN, M. AND P. JORDAN. *Elementare Quantenmechanik* Berlin.
461. BROWNE, E. T.: On the separation property of the roots of the secular equation. *Amer. Journ. Math.* 52, 843-850.
462. BROWNE, E. T.: The characteristic roots of a matrix. *Bull. Amer. Math. Soc.* 36, 705-710.
463. DIENES, P.: The exponential function in linear algebras. *Quart. Journ.* (2) 1, 300-309.
464. INGRAHAM, M. H.: An elementary theorem on matrices. *Bull. Amer. Math. Soc.* 36, 673-674.
465. LAURA, E.: La teoria delle matrici e il metodo dell' n -edro mobile. *Rend. Sem. Mat. Padova* 1, 85-109.
466. LOEWY, A. AND R. BRAUER. Über einen Satz für unitäre Matrizen. *Tôhoku Math. Journ.* 32, 44-49.
467. MEHMKE, R.: Praktische Lösung der Grundaufgaben über Determinanten, Matrizen und lineare Transformationen. *Math. Ann.* 103, 300-318.
468. MEHMKE, R.: Berichtigung, das Aufstellung der identischen Gleichung einer Matrix betreffend. *Math. Ann.* 104, 167-168.
469. MUIR, T.: The literature of Cayleyan matrices. *Trans. Roy. Soc. So. Africa* 18, 219-225.
470. NOWLAN, F. S.: On the direct product of a division algebra and a total matrix algebra, (1927). *Bull. Amer. Math. Soc.* 36, 265-268.
471. PERRON, O.: Über eine Matrixtransformation. *Math. Zeits.* 32, 465-473.
472. RASCH, G.: Om systemer af lineære differentiaalligninger. *Svende Skandin. Mat. Kongr.*, 1929, 117-126.
473. RASCH, G.: Om matrixregning og dens anvendelse paa differens- og differentiaalligninger. *Diss. Copenhagen.*
474. ROTH, W. E.: On the unilateral equation in matrices, (1929). *Trans. Amer. Math. Soc.* 32, 61-80.
475. TOCCHI, L.: Sulla caratteristica delle matrici. *Giorn. di Mat.* 68, 201-217.
476. WELLSTEIN, J.: Über symmetrische, alternierende und orthogonale Normalformen von Matrizen. *Crelle* 163, 166-182.

1931

477. AITKEN, A. C.: Further studies in algebraic equations and matrices. *Proc. Roy. Soc. Edinb.* 51, 80-90.
478. ALBERT, A. A.: The structure of matrices with any normal division algebra of multiplications, (1930). *Annals of Math.* 32, 131-148.
479. CECIONI, F.: Sull'equazione fra matrici $AX = XA$. *Ann. Univ. Toscane* 14, fasc. 2, 1-49.
480. FINAN, E. J.: A determination of the domains of integrity of the complete rational matrix algebra of order 4. *Amer. Journ. Math.* 53, 920-928.
481. FRANKLIN, P.: Algebraic matrix equations. *Journ. Math. Phys.* 10, 289-314.
482. GALANTI, G.: Algoritmi di calcolo motoriale. *Accad. Lincei Rend.* (6) 13, 861-866.
483. HASSE, H.: Über p -adische Schiefkörper und ihre Bedeutung für die Arithmetik hyperkomplexer Zahlensysteme. *Math. Ann.* 104, 495-534.
484. KLEIN, F.: Über rechteckige Matrizen, bei denen die Determinanten maximaler Reihenanzahl teilerfremd zu einem Modul sind. *Jbr. Deutsch. Math. Ver.* 40, 233-238.

485. KRAVČUK, M. AND A. SMOGORZEWSKIJ: Sur les transformations unitaires et orthogonales. *Journ. Cycle Math.* 1, 3-41.
486. KRAVČUK, M.: Sur une inégalité. *Bull. Acad. Sci. Ukraine* 1, 96-101.
487. LITTLEWOOD, D. E.: Identical relations satisfied in an algebra, (1930). *Proc. Lond. Math. Soc.* (2) 32, 312-320.
488. MACDUFFEE, C. C.: The discriminant matrices of a linear associative algebra, (1930). *Annals of Math.* 32, 60-66.
489. MACDUFFEE, C. C.: The discriminant matrix of a semi-simple algebra, (1930). *Trans. Amer. Math. Soc.* 33, 425-432.
490. MURNAGHAN, F. D.: On the representation of a Lorentz transformation by means of two-rowed matrices. *Amer. Math. Monthly* 38, 504-511.
491. MURNAGHAN, F. D., AND A. WINTNER: A canonical form for real matrices under orthogonal transformations. *Proc. Amer. Nat. Acad. Sci.* 17, 417-420.
492. NOWLAN, F. S.: A note on primitive idempotent elements of a total matrix algebra, (1927). *Bull. Amer. Math. Soc.* 37, 854-856.
493. ROMANOVSKY, V.: Sur les zéros des matrices stochastiques. *Comptes Rendus* 192, 266-269.
494. SCHLESINGER, L.: Neue Grundlagen für einen Infinitesimalkalkül der Matrizen, (1929). *Math. Zeits.* 33, 33-61.
495. SPAMPINATO, N.: Algebre elementari, teoria delle semialgebre e cicli pseudoriemanniani. *Note Esercit. Mat.* 6, 107-245.
496. TAKAHASHI, S.: On the roots of the characteristic equation of a certain matrix. *Proc. Imp. Acad. Tokyo* 7, 241-243.
497. THOMAS, J. M.: Matrices of integers ordering derivatives. *Trans. Amer. Math. Soc.* 33, 389-410.
498. THURSTON, H. S.: On the characteristic equations of products of square matrices. *Amer. Math. Monthly* 38, 322-324.
499. THURSTON, H. S.: The characteristic equations of the adjoint and the inverse of a matrix. *Amer. Math. Monthly* 38, 448-449.
500. TURNBULL, H. W.: The invariant theory of a general bilinear form, (1930). *Proc. Lond. Math. Soc.* (2) 33, 1-21.
501. TURNBULL, H. W.: Matrix differentiation of the characteristic function. *Proc. Edinb. Math. Soc.* (2) 2, 256-264.
502. WARD, M.: The algebra of recurring series, (1930). *Annals of Math.* 32, 1-9.
503. WEDDERBURN, J. H. M.: Non-commutative domains of integrity. *Crelle* 167, 129-141.
504. WILLIAMSON, J.: Bazin's matrix and other allied matrices. *Proc. Edinb. Math. Soc.* (2) 2, 240-251.
505. WILLIAMSON, J.: The latent roots of a matrix of special type. *Bull. Amer. Math. Soc.* 37, 585-590.
506. WINTNER, A., AND F. D. MURNAGHAN: On a polar representation of non-singular matrices. *Proc. Amer. Nat. Acad. Sci.* 17, 676-678.

1932

507. AMATO, V.: Sulla risoluzione di equazioni nel campo delle matrici complesse. *Boll. Accad. Gioenia, Catania, Ser. (2), fasc. 62*, 50-55.
508. BOTTEMA, O.: Over machtreekseen van matrices. *Nieuw Arch. Wisk.* 17, 114-118.
509. BUSH, L. E.: Note on the discriminant matrix of an algebra, (1931). *Bull. Amer. Math. Soc.* 38, 49-51.
510. CIPOLLA, M.: Sulle matrici espressioni analitiche di un'altra. *Rend. Circ. Mat. Palermo* 56, 144-154.
511. EDDINGTON, A. S.: On sets of anti-commuting matrices, (1931). *Journ. Lond. Math. Soc.* 7, 58-68.

512. MENGE, W. O.: On the rank of the product of certain square matrices, (1930). Bull. Amer. Math. Soc. 38, 88-94.
513. MITCHELL, A. K.: On a matrix differential operator. Bull. Amer. Math. Soc. 38, 251-254.
514. MURNAGHAN, F. D.: On the unitary invariants of a square matrix. Proc. Amer. Nat. Acad. Sci. 185-189.
515. MURSI-AHMED, M.: On the composition of simultaneous differential systems of the first order. Proc. Edinb. Math. Soc. (2) 3, 128-131.
516. NEWMAN, M. H. A.: Note on an algebraic theorem of Eddington. Journ. Lond. Math. Soc. 7, 93-99.
517. PIERCE, T. A.: The practical evaluation of resultants. Amer. Math. Monthly 39, 161-162.
518. RUTHERFORD, D. E.: On the solution of the matrix equation $AX + XB = C$. Akad. Wet. Amsterdam Proc. 35, 54-59.
519. RUTHERFORD, D. E.: On the canonical form of a rational integral function of a matrix. Proc. Edinb. Math. Soc. (2) 3, 135-143.
520. RUTHERFORD, D. E.: On the rational commutant of a square matrix. Proc. Akad. Wet. Amsterdam 35, 870-875.
521. SCHLESINGER, L.: Weitere Beiträge zum Infinitesimal-kalkül der Matrizen, (1931). Math. Zeits. 35, 485-501.
522. SCHREIER, O., AND E. SPERNER: Vorlesungen über Matrizen. Leipzig.
523. SMOHORSHEVSKY, A.: Sur les matrices unitaires du type de circulants. Journ. Cycle Math. 2, 89-90.
524. TAKAHASHI, S.: Zum verallgemeinerten Infinitesimal-kalkül der Matrizen. Jap. Journ. Math. 9, 27-46.
525. TURNBULL, H. W., AND A. C. AITKEN: An introduction to the theory of canonical matrices. Edinburgh.
526. WEITZENBÖCK, R.: Über die Matrixgleichung $AX + XB = C$. Proc. Akad. Wet. Amsterdam 35, 60-61.
527. WEITZENBÖCK, R.: Über die Matrixgleichung $X^2 = A$. Proc. Akad. Wet. Amsterdam 35, 157-161.
528. WEITZENBÖCK, R.: Über die Matrixgleichung $XX' = A$. Proc. Akad. Wet. Amsterdam 35, 328-330.
529. WILLIAMSON, J.: The product of a circulant matrix and a special diagonal matrix. Amer. Math. Monthly 39, 280-285.
530. WILSON, R.: Elimnants of the characteristic equations. Proc. Lond. Math. Soc. (2) 33, 517-524.

1933

531. EDDINGTON, A. S.: On sets of anticommuting matrices. II. The factorization of E -numbers. Journ. Lond. Math. Soc. 8, 142-152.
532. HENSEL, K.: Über die Ausführbarkeit der elementaren Rechenoperationen in Ringen von Systemen. Crelle 169, 67-70.
533. MACDUFFEE, C. C.: Matrices with elements in a principal ideal ring. Bull. Amer. Math. Soc. 39, 564-584.
534. MACDUFFEE, C. C.: The theory of matrices. Berlin.
535. MENGE, W. O.: Construction of transformations to canonical forms. Amer. Journ. Math. 55, 671-682.
536. MILNE-THOMSON, L. M.: A matrix representation of ascending and descending continued fractions, (1932). Proc. Edinb. Math. Soc. (2) 3, 189-200.
537. RÖSELER, H.: Normalformen von Matrizen gegenüber unitären Transformationen. Diss. Darmstadt.

538. ROMANOVSKY, V.: Un théorème sur les zéros des matrices non négative. Bull. Soc. Math. France 61, 213-219.
539. ROTH, W. E.: On the equation $P(A, X) = 0$ in matrices. Trans. Amer. Math. Soc. 35, 689-708.
540. RUTHERFORD, D. E.: On the condition that two Zehfuss matrices be equal. Bull. Amer. Math. Soc. 39, 801-808.
541. RUTHERFORD, D. E.: On the rational solution of the matrix equation $SX = XT$. Proc. Akad. Wet. Amsterdam 36, 432-442.
542. SOKOLNIKOFF, E. S.: Matrices conjugate to a given matrix with respect to its minimum equation. Amer. Journ. Math. 55, 167-180.
543. TURNBULL, H. W.: Diagonal matrices. Proc. Cambr. Phil. Soc. 29, 347-372.
544. TURNBULL, H. W.: Matrices and continued fractions, II. Proc. Roy. Soc. Edinb. 53, 208-219.
545. WEGNER, U.: Über die Frobeniusschen Kovarianten. Monatsh. Math. Phys. 40, 201-208.
546. WEGNER, U. AND J. WELLSTEIN: Bemerkungen zur Transformation von Komplexen symmetrischen Matrizen. Monatsh. Math. Phys. 40, 319-322.
547. WILLIAMSON, J.: The expansion of determinants of composite order. Amer. Math. Monthly 40, 65-69.
548. WILLIAMSON, J.: Sets of semi-commutative matrices, (1932). Proc. Edinb. Math. Soc. (2) 3, 179-188.
549. WILLIAMSON, J.: Matrices whose sth compounds are equal. Bull. Amer. Math. Soc. 39, 108-111.

INDEX TO BIBLIOGRAPHY

- Aitken, A. C., 412, 413, 477, 525
 Albert, A. A., 455, 456, 457, 478
 Amaldi, U., 180, 295
 Amante, S., 458
 Amato, V., 319, 507
 Aramata, K., 400
 Autonne, L., 199, 200, 210, 211, 212, 213, 214,
 239, 262, 278, 296, 304, 320

 Bachmann, P., 164
 Baker, H. F., 150, 174, 215, 216, 226
 Ball, R., 263
 Beck, H., 390
 Beckenbach, E. F., 441
 Bell, E. T., 459
 Bendixson, J., 181, 201
 Bennett, A. A., 349
 Birkhoff, G. D., 305, 326, 372
 Bliss, G. A., 310
 Bôcher, M., 247
 Boehm, K., 321
 Born, M., 385, 391, 460
 Bose, A. C., 352
 Bottema, O., 508
 Brahana, H. R., 373
 Brauer, R., 414, 466
 Brill, J., 128, 137, 151, 248
 Bromwich, T. J. l'A., 187, 188, 189, 190, 191,
 233, 240
 Browne, E. T., 415, 461, 462
 Brunel, G., 76
 Buchheim, A., 39, 40, 59, 60, 61, 69, 72, 73, 77,
 81, 192
 Burgatti, P., 416
 Burgess, H. T., 285, 286, 327, 328, 340
 Burnside, W., 202, 227
 Bush, L. E., 509

 Carlini, L., 193, 203
 Cartan, E., 253
 Carvallo, E., 88
 Cayley, A., 2, 3, 7, 12, 22, 23, 62, 63, 70, 89, 90
 Cecioni, F., 264, 265, 279, 479
 Chapman, C. H., 91
 Châtelet, A., 287
 Cherubino, S., 442, 443
 Cipolla, M., 311, 510

 Clifford, W. K., 27
 Coolidge, J. L., 353
 Cullis, C. E., 306, 329, 336, 341, 358, 386
 Cunningham, E., 234

 David, L., 288
 Dhar, S., 364
 Dickson, L. E., 204, 266, 312, 374, 380, 392,
 401, 417
 Dienes, P., 463
 Drach, J., 297
 Dubnov, J. S., 393

 Eddington, A. S., 511, 531
 van Elfrinkhof, L., 101, 102, 129, 130
 Élie, B., 109, 289

 Fantappiè, L., 418
 Finan, E. J., 480
 Fischer, E., 402
 Forsyth, A. R., 41
 Franklin, F., 116
 Franklin, P., 370, 481
 Frisch, R., 403
 Frobenius, G., 18, 19, 20, 24, 25, 138, 139,
 140, 217, 254, 267, 280, 290, 291, 292, 298

 Galanti, G., 482
 Gamberini, G., 268, 270
 Ghosh, N., 354
 Gibbs, J. W., 74, 194, 241
 Giorgi, C., 419, 420
 Grassmann, H., 5

 Hamilton, W. R., 1, 4, 6, 8
 Hasse, H., 375, 483
 Hawkes, H. E., 281
 Heisenberg, W., 391
 Hensel, K., 131, 205, 228, 394, 421, 532
 Hilton, H., 299, 300, 301, 302, 307, 313, 314
 Hitchcock, F. L., 365, 376
 Hirsch, A., 206
 Hudson, R. W. H. T., 218
 Hurwitz, A., 117
 Hutchinson, J. I., 282

 Ingraham, M. H., 464

- Jackson, D., 271
 Joly, C. J., 132, 141, 142, 165, 195, 219, 220,
 235
 Jordan, P., 385, 391, 460

 Kagan, V. F., 395
 Karst, L., 272
 Klein, F., 484
 Kowalewski, G., 337, 422
 Kravcuk, M., 322, 381, 382, 404, 485, 486
 Kreis, H., 242, 255, 283
 Kronecker, L., 92
 Krull, W., 359, 396
 Kürschák, J., 383, 387
 Kumamoto, A., 71

 Laguerre, E. N., 9
 Laisant, C.-A., 26
 Landsberg, G., 143, 205
 Langer, R. E., 372
 Lattès, S., 303, 323, 330
 Laura, E., 465
 Laurent, H., 144, 152, 166, 229
 Leveugle, R., 355
 Levi, B., 331
 Littlewood, D. E., 487
 Loewy, A., 153, 154, 167, 168, 182, 183, 196,
 284, 308, 338, 342, 343, 356, 466
 Logsdon, M. I., 366

 McAulay, A., 110
 MacDuffee, C. C., 397, 423, 444, 445, 488,
 489, 533, 534
 Martis, S., 424, 425, 426, 446
 Mehmke, R., 377, 467, 468
 Menge, W. O., 512, 535
 Metzler, W. H., 103, 111, 118, 119, 120, 315
 Meyer, W. F., 297
 Milne-Thomson, L. M., 536
 Mitchell, A. K., 513
 Molenbroek, P., 93
 Molien, T., 104
 Moore, C. L. E., 34
 Morrice, G., 78
 Muir, T., 64, 169, 345, 384, 469
 Murnaghan, F. D., 490, 491, 506, 514
 Mursi-Ahmed, M., 515
 Muth, P., 175, 236

 v. Neumann, J., 405
 Newman, M. H. A., 516
 Niccolletti, O., 207, 256
 Nowlan, F. S., 470, 492

 Ory, H., 427

 Peano, G., 75, 121
 Peirce, B., 17
 Peirce, C. S., 28, 34, 35
 Perron, O., 249, 324, 471
 Petr, K., 243, 244
 Phillips, H. B., 344, 350
 Pidduck, F. B., 357
 Pierce, T. A., 517
 Pillai, S. S., 447
 Pincherle, S., 145
 Plarr, G., 21, 29
 Plemelj, J., 197
 Polya, G., 428
 Porcu-Tortrini, E., 406, 407, 408, 429

 Rabinovic, J., 293
 Radon, J., 367
 Rados, G., 94, 105, 106, 146, 147, 170, 176,
 221, 222
 Ranum, A., 257, 294
 Rasch, G., 472, 473
 Ravut, L., 171
 Riley, J. L., 398
 Röseler, H., 537
 Romanovsky, V., 493, 538
 Rost, G., 107
 Roth, W. E., 430, 448, 474, 539
 Rutherford, D. E., 518, 519, 520, 540, 541

 Schlesinger, L., 133, 184, 237, 258, 449, 494,
 521
 Schreier, O., 522
 Schrutka, L., 431
 Schur, I., 198, 208, 238, 273, 368, 388, 409
 Scorza, G., 332, 346, 360, 361, 362, 450
 de Séguier, J. A., 230, 250, 259, 260, 274
 Sforza, G., 122
 Shaw, J. B., 155, 177, 223, 251, 369
 Shoda, K., 451
 Smohorshevsky, A., 485, 523
 Sokolnikoff, E. S., 542
 Spampinato, N., 410, 495
 Speiser, A., 351
 Sperner, E., 522
 Stein, J., 316
 Stephanos, C., 172, 178, 185
 Study, E., 95, 179, 253, 347
 Sylvester, J. J., 30, 31, 32, 33, 36, 37, 38, 42,
 43, 44, 45, 46, 47, 48, 49, 50, 51, 52, 53, 54,
 55, 56, 57, 58, 65, 82
 Szász, O., 339, 363

- Taber, H., 84, 96, 97, 98, 99, 112, 113, 114, 115,
123, 124, 125, 126, 134, 135, 148, 149,
156, 157, 158, 231, 333
- Tait, P. G., 10, 11, 13, 14, 15, 16, 159, 160,
161, 186
- Takahashi, S., 496, 524
- Thomas, J. M., 497
- Thurston, H. S., 498, 499
- Tocchi, L., 475
- Toeplitz, O., 348
- Toscano, L., 432, 433, 452
- Tsuji, M., 453
- Turnbull, H. W., 411, 434, 435, 436, 500, 501,
525, 543, 544
- Vaidyanathaswamy, R., 437, 438
- Veblen, O., 370
- Voghera, G., 439
- Volterra, V., 209
- Voss, A., 85, 86, 108, 162, 163
- Ward, M., 502
- Wedderburn, J. H. M., 224, 232, 245, 252,
309, 317, 318, 325, 371, 389, 399, 503
- Wegner, U., 545, 546
- Weinstein, A., 378
- Weitzenböck, R., 526, 527, 528
- Wellstein, J., 225, 275, 276, 476, 546.
- Weltzien, C., 379
- van Wettum, T. B., 87, 100, 127, 136
- Weyl, H., 440
- Weyr, E., 66, 67, 68, 79, 80, 83
- Whitehead, A. N., 173
- Whittaker, E. T., 334
- Widder, W., 277, 335
- Williamson, J., 504, 505, 529, 547, 548, 549
- Wilson, E. B., 194, 261
- Wilson, R., 530
- Wintner, A., 454, 491, 506
- Wirth, J., 246

INDEX

- Absolute value, 125 ff., 171
- Adjoint, 7, 66
- Algebraic functions, 119
- Algebras, 147 ff.
 - basis of, 148
 - classification of, 158
 - difference, 153
 - division, 147, 159, 162
 - group, 167
 - index of, 153
 - matrix, 156, 159
 - matrix representation of, 149
 - nilpotent, 153
 - radical of, 154, 157 ff.
 - semi-simple, 154, 159 ff., 168
 - simple, 154, 159 ff.
- Associated matrix, 76 ff., 96
 - determinant of, 79
 - irreducible, 85
- Associative algebra, 147
- Automorphic transformation, 140 ff., 171

- Baker, H. F., 170
- Basis, 2, 10, 11, 13, 73, 148, 150
 - change of, 9
 - canonical, 54
 - fundamental, 3, 11
 - linear elementary, 52
 - normal, 49, 55
 - orthogonal, 12
 - reciprocal, 11
 - unitary, 13
- Bibliography, 172
 - index to, 194
- Bilinear form, 9, 68 ff., 128, 140
- Bordered determinant, 67
- Born, M., 135

- Canonical basis, 54, 55
 - form, 41, 62, 90
 - of a function, 166
 - rational, 123
- Cayley, 169, 170, 171
- Chain, 44, 55
- Characteristic, 39
 - equation, 23, 112, 169
 - function, 23, 24
- Christoffel symbols, 133
- Classification of algebras, 158
- Cogredient transformation, 98 ff.
- Commutative matrices, 20, 27, 102 ff.
- Complement, 64
- Complementary subspace, 3, 50
- Complex, 150
- Components, 1
- Compound matrices, 64 ff.
 - determinant of, 66
 - roots of, 67
 - supplementary, 65, 126
- Contravariant vector, 132
- Coordinates, 1, 4, 72
- Covariant differential operator, 134
 - vector, 132

- Decomposable representation, 165 ff.
- Definite, 92, 100
- Degree invariants, 48
- Derivative, 128
 - covariant, 135
- Determinants, 7, 64, 66, 67
 - bordered, 67
 - compound, 69
 - vector, 73, 170
- Dextrolateral, 115, 130
- Dickson, L. E., 170
- Difference algebra, 153
- Differential, 131
- Differential operator, 131, 135
 - covariant, 134
- Differentiation formulae, 136
- Direct product, 74, 108, 151, 158
 - sum, 151, 161
- Division algebra, 147, 159, 162
- Division of polynomials, 21
- Divisors, elementary, 38 ff., 88, 92, 93, 105, 125

- Elementary divisors, 38 ff., 93, 105
 - of matrix, 39, 93, 125
 - of hermitian matrix, 88
 - of real skew-matrix, 88
 - of real symmetric matrix, 88, 93
 - of orthogonal matrix, 92
 - of unitary matrix, 92

- Elementary transformation, 33 ff., 47, 169
 integral set, 50
 linear set, 52 ff.
 polynomial, 21, 50
 set, 49
- Equation, characteristic, 23, 112
 reduced, 24.
 $y^m = x$, 119
- Equivalent, 34, 47, 76, 85, 100
 strictly, 48, 55, 61, 99
- Exponential function, 116, 122, 171
- Factors, determinantal, 36
 invariant, 36, 37, 52, 71, 107, 170
- Field, 1, 147
- Forms, bilinear, 9, 68 ff., 128, 140
 hermitian, 92, 94
- Francke, 69
- Frobenius, 106, 150, 169, 170
- Function, algebraic, 119
 canonical form, 116
 characteristic, 23, 32
 exponential, 116, 122, 171
 Kronecker delta, 6
 linear vector, 3
 logarithmic, 116, 122
 of matrix variable, 115, 135
 of commutative matrices, 110
 of matrix, 26, 28, 29, 30, 115 ff.
 of scalar variable, 128
 of vector variable, 130, 132
 reduced characteristic, 24
- Fundamental basis, 3
 unit matrices, 5
- Grade, 16, 73, 74
- Grassmann, 16, 64, 169, 170, 171
- Ground of matrix, 15, 61
- Group algebra, 167
- Hadamard, 126
- Hamilton, 131, 169, 170, 171
- Hamiltonian function, 137
- Hermite, 171
- Hermitian forms, 92 ff.
 matrices, 88 ff.
 elementary divisors, 88, 93
 invariant vectors, 90
 rank, 89
 roots, 88, 170
 signature, 95
- Hilton, H., 170
- Hurwitz, A., 170
- Hypernumber, 1, 72
- Idempotent elements, 29, 42, 154, 162
 matrix, 7, 29
- Identities, 20, 111
- Identity matrix, 5
- Index, of algebra, 153
 of chain, 55
 of nilpotent matrix, 7
- Induced matrix, 75
- Infinite products, 127, 171
 series, 115
- Integral, 129
- Integral set, 47 ff., 120
 elementary, 50, 52
- Interpolation formula, 26, 28
- Intersection, 150
- Invariant, 48
 degree, 48
 factors, 36, 38, 52, 71, 107, 170
 Kronecker, 55
 of hermitian matrix, 90
 subalgebra, 152, 161
 subspaces, 166
 vectors, 43 ff., 169, 170
- Irreducible transformable sets, 85
 algebra, 161
- Jacobian matrix, 132
- Kronecker, 99, 170
 delta function, 6
 invariants, 55
 reduction, 96
- Laevolateral, 115, 130
- Lagrange, 25, 68
- Laguerre, 169, 171
- Laplace, 63, 66
- Latent roots, 24
- Linear algebra, 147 ff.
 dependence, 2, 10, 16
 elementary bases, 52
 polynomial, 37 ff., 170
 singular, 55 ff., 170
 set, 2, 19
 transformable, 80
 transformation, 1
 vector function, 3
- Loewy, A., 170, 171
- Logarithm, 116, 122

- McAulay, A., 135
 Matric function of scalar variable, 128
 polynomials in scalar variable, 20, 21, 22,
 24, 27, 29, 30, 33 ff., 71, 115, 130
 invariant factors, 36
 linear, 37 ff., 55 ff.
 normal form, 34
 representation of algebra, 149
 subalgebras, 156, 159
 Matrix, 3, 169
 adjoint, 7
 associated, 76
 compound, 64
 conjugate, 8
 hermitian, 88
 induced, 75
 Jacobian, 132
 orthogonal, 12
 power, 75
 product transformation, 75
 scalar, 5, 6
 skew, 8, 88, 91
 symmetric, 8, 88, 90
 transposed, 8
 transverse, 8, 9
 unitary, 13
 Muir, 169
 Muth, 170

 Nilpotent algebra, 153
 matrix, 7
 Normal basis, 49, 55
 form, 34
 Nullity, 15, 169
 Nullspace, 15, 43, 45, 69

 Operator, covariant differential, 134
 matric differential, 135
 vector differential, 131
 Order of complex, 150
 of set, 2
 Orthogonal basis, 12
 matrix, 12, 90, 91, 92, 142

 Partial elements, 42
 Peano, 171
 Peirce, 169
 Permanent, 75
 Pole, 43
 Polynomial, elementary, 21, 50
 linear, 37 ff., 55 ff.
 matric, 20, 24, 25, 26, 33 ff., 115
 normal form, 34
 scalar, 26, 28, 30, 106
 vector, 47 ff.
 Power matrix, 75
 Powers of matrix, 6, 26, 120
 Primitive idempotent element, 155, 162
 Principal idempotent elements, 29
 nilpotent elements, 29
 unit, 147, 155
 Product of complexes, 150
 direct, 74, 108, 151, 158
 infinite, 127, 171
 of matrices, 4
 of tensors, 72
 scalar, 9, 63
 transformation, 75

 Quasi-hermitian forms, 92 ff.
 Quasi-orthogonal, 93

 Radical, 154, 157 ff.
 Rados, 170
 Rank, 14, 16, 34, 69, 96, 169
 hermitian matrix, 89, 94
 Reciprocal bases, 11
 Reduced characteristic function, 24, 32
 equation, 24
 Reducible matrix, 31, 77
 representation, 165, 167
 Reduction of bilinear forms, 68
 hermitian forms, 93, 96
 quadratic forms, 93, 96
 Regular matrix, 7
 representation, 166, 167
 Remainder theorem, 22, 169
 Representation of algebra, 149, 165
 Roots of associated matrix, 79
 commutative matrices, 111
 compound matrix, 67
 permutian matrix, 88, 170
 matric function, 26, 29, 30, 111
 matrix, 24, 27
 orthogonal matrix, 91
 skew matrix, 91, 170
 symmetric matrix, 88, 170
 unitary matrix, 91
 0 and 1, 118, 171

 Scalar, 1, 9, 63, 81
 matrix, 5, 6
 polynomials, 26, 28, 30
 Schur, I., 170
 Semi-definite, 92
 Semi-simple algebra, 154, 158 ff., 168

- Series, infinite, 115
 Set, elementary, 49, 52, 55
 integral, 47 ff.
 linear, 2, 19
 transformable, 80, 85
 order of, 2
 Signature, 95, 100
 Similar matrices, 11, 25, 38, 41, 113, 141
 linear elementary sets, 55
 Simple algebra, 154 ff.
 Singular, 7, 158
 Skew matrix, 8, 93, 96, 99, 142
 real, 88, 91
 Smith, 170
 Square root, 30, 118, 169
 Stephanos, 170
 Subalgebra, invariant, 152, 161
 matrix, 156 ff.
 semi-invariant, 163 ff.
 Subspace, 2
 complementary, 3
 Supplementary compound, 65, 126
 Sum of complexes, 150
 of matrices, 4
 Sylvester, 69, 80, 111, 113, 169, 170, 171
 Sylvester's identities, 111
 Symmetric matrices, 8, 93, 95, 96, 99, 101, 142
 real, 88, 90, 95

 Taber, 135, 170, 171
 Tait, 170
 Tensor, 73
 absolute value, 127
 product, 72
 scalar product, 81

 Trace, 26, 125, 135, 136, 150, 155
 Transform, 11
 Transformable linear sets, 80, 85
 systems, 79
 Transformation, automorphic, 140 ff., 171
 cogredient, 98
 elementary, 33 ff., 47, 169
 product, 75
 Transverse, 8, 9, 11, 141
 Turnbull, H. W., 135

 Unit matrices, 5, 11, 108, 169
 principal, 147, 155, 156, 161
 tensor, 73
 vector, 3
 Unitary basis, 13
 matrix, 13, 90, 91, 92

 Vector, 1, 74
 complement, 64
 contravariant, 132
 covariant, 132
 invariant, 43, 90, 169, 170
 function of, 130, 132
 grade, 16, 74
 polynomials, 47 ff.
 product, 72
 pure, 16, 74
 scalar product, 9
 unit, 3
 Voss, 171

 Weierstrass, 170
 Weyl, H., 86, 170

1903

- 214 (a) BAKER, H. F.: On the integration of linear differential equations (1902). Proc. Lond. Math. Soc. 35, 333-378.
- 220 (a) KRONECKER, L.: Vorlesungen über die Theorie der Determinante (1883-1891). Leipzig.

1922

- 363 (a) BENNETT, A. A.: Some algebraic analogues in matric theory. Annals of Math. (2) 23, 91-96.
- 364 (a) FRANKLIN, F.: Generalized conjugate matrices. Annals of Math. (2) 23, 97-100.

1925

- 386 (a) HILTON, H.: (Question 2165). Intermédiaire Math. (2) 4, 106-107.

1927

- 399 (a) ANDREOLI, G.: Sulla teoria di certi determinanti decomponibili in fattori, e sulle teoria delle algebre. Note Eserc. Mat. Catania 5, 22-35, 105-115.

1931

- 489 (a) MITCHELL, A. K.: A note on the characteristic determinant of a matrix. Amer. Math. Monthly 38, 386-388.
- 494 (a) SMITH, T.: Tesserai matrices. Quart. Journ. (2) 2, 241-251.

1932

- 509 (a) CAUER, W.: Über Funktionen mit positiven Realteil (1931). Math. Ann. 106, 369-394.
- 511 (a) KRISHNAMURTHY RAO, S.: Invariant-factors of a certain class of linear substitutions. Journ. Indian Math. Soc. 19, 233-240.
- 511 (b) KRULL, W.: Matrizen, Moduln und verallgemeinerte Abelsche Gruppen im Bereich der ganzen algebraischen Zahlen. Sitzb. Heid. Akad. Wiss., Math-Nat. Kl. 1932, Abh. 2, 13-38.
- 511 (c) NEWMAN, M. H. A.: Note on an algebraic theorem of Eddington. Journ. Lond. Math. Soc. 7, 93-99, 272.

1933

- 530 (a) AITKEN, A. C.: On the canonical form of the singular matrix pencil. Quart. Journ. Math. (2) 4, 241-245.
- 530 (b) AMANTE, S.: Sulla riduzione a forma canonica di una classe speciale di matrici. R. Accad. Lincei Rend. (6) 17, 31-36, 431-436.
- 536 (a) MITCHELL, A. K.: The Cayley-Hamilton theorem. Amer. Math. Monthly 40, 153-154.
- 545 (a) WEGNER, U.: The product of a circulant matrix and a special diagonal matrix. Amer. Math. Monthly 40, 23-25.
- 548 (a) WILLIAMSON, J.: Sets of semi-commutative matrices. Proc. Edinb. Math. Soc. (2) 3, 179-200, 231-240.

1934

- 550 AITKEN, A. C.: The normal form of compound and induced matrices. Proc. Lond. Math. Soc. (2) 38, 354-376.
- 551 ALBERT, A. A.: On the construction of Riemann matrices I (1933). Annals of Math. (2) 35, 1-28.
- 552 ALBERT, A. A.: A solution of the principal problem in the theory of Riemann matrices. Annals of Math. (2) 35, 500-515.
- 553 ALBERT, A. A.: The principal matrices of a Riemann matrix. Bull. Amer. Math. Soc. 40, 843-846.

- 554 DUNCAN, W. J., and A. R. COLLAR: A method for the solution of oscillation problems by matrices. *Phil. Mag.* (7) 17, 865-909.
- 555 FRANZ, W.: Elementarteilerttheorie in algebraischen Zahlkörper. *Journ. reine angew. Math.* 171, 149-161.
- 556 HERMANN, A.: Über Matrixgleichungen und die Zerlegung von Polynomen in Linearfaktoren. *Compositio Math.* 1, 284-302.
- 557 HOPKINS, C.: An elementary proof of the theorem that the most general matrix commutative with a given n -rowed square matrix involves at least n arbitrary parameters. *Tôhoku Math. Journ.* 39, 358-360.
- 558 JACOBSTHAL, E.: Zur Theorie der linearen Abbildungen. *Sitzb. Berl. Math. Ges.* 33, 15-34.
- 559 KÖNIG, K.: Die Vektormatrizen als Verallgemeinerung der Quaternionen. *Mitt. Math. Ges. Hamburg* 7, 232-237.
- 560 LITTLEWOOD, D. E.: Note on the anticommuting matrices of Eddington. *Journ. Lond. Math. Soc.* 9, 41-50.
- 561 MCCOY, N. H.: On quasi-commutative matrices. *Trans. Amer. Math. Soc.* 36, 327-340.
- 562 METZLER, W. H.: A new theorem concerning the rank of a matrix. *Amer. Math. Monthly* 41, 607-608.
- 563 NAKANO, H.: Über die Matrixfunktion. *Jap. Journ. Math.* 11, 9-13.
- 564 NOWLAN, F. S.: Transformations which leave invariant the multiplication table of a total matrix algebra. *Tôhoku Math. Journ.* 39, 372-379.
- 565 PIRNE, K.: Regning med matriser. *Norsk Mat. Tidsskr.* 16, 33-55.
- 566 RASCH, G.: Zur Theorie und Anwendung des Produktintegrals. *Journ. reine angew. Math.* 171, 65-119.
- 567 ROTH, W. E.: On direct product matrices. *Bull. Amer. Math. Soc.* 40, 461-468.
- 568 RUSAM, F.: Matrizenringe mit Koeffizienten aus Ringen ganzer Zahlen. *Diss. Erlangen* 1934.
- 569 SCORZA, G.: Sulla riduzione a forma canonica di una classe speciale di matrici. *Rend. Accad. Sci. Fis. Mat. Napoli* (4) 4, 154-156.
- 570 SCHWABDRFEBGER, H.: Sur les racines caractéristiques des matrices de formes linéaires. *Comptes Rendus* 199, 508-510.
- 571 SEITZ, F.: A matrix-algebraic development of the crystallographic groups. I. *Zeits. Kristall.* A 88, 433-459.
- 572 SZÜCS, A.: Sur les équations définissant une matrice en fonction algébrique d'une autre. *Acta Litt. Sci. Szeged* 7, 48-50.
- 573 TROTT, G. R.: On the canonical form of a non-singular pencil of Hermitian matrices. *Amer. Journ. Math.* 56, 359-371.
- 574 TURNBULL, H. W.: Power vectors, *Proc. Lond. Math. Soc.* (2) 37, 106-146.
- 575 WEDDERBURN, J. H. M.: *Lectures on matrices.* New York.
- 576 WEYL, H.: On generalized Riemann matrices. *Annals of Math.* (2) 35, 714-729.
- 577 WHYBURN, W. M.: Matrix differential equations. *Amer. Journ. Math.* 56, 587-592.
- 578 WINTNER, A.: Über die automorphen Transformation beschränkter nicht-singuläre hermitscher Formen. *Math. Zeits.* 38, 695-700.
- 1935
- 579 ALBERT, A. A.: Involutional simple algebras and real Riemann matrices. *Annals of Math.* (2) 36, 886-964.
- 580 ANDREOLI, G.: Sulle funzioni di composizione di matrici. (Funzioni isogene.) *Atti Accad. Sci. Fis. Mat. Napoli* (2) 20, no. 10, 1-31.
- 581 BROWNE, E. T.: On the matrix equations $P(X)=A$ and $P(A, X)=O$. *Bull. Amer. Math. Soc.* 41, 737-743.

- 582 BURINGTON, R. S.: Matrices in electric circuit theory. *Journ. Math. Phys.* 14, 325-349.
- 583 CHERUBINO, S.: Sul rango delle matrici pseudonulle. *Boll. Un. Mat. Ital.* 14, 143-149.
- 584 CHERUBINO, S.: Sopra un teorema particolare e sui due fondamentali nella teoria delle matrici. *Boll. Un. Mat. Ital.* 14, 230-234.
- 585 CHERUBINO, S.: Sulle matrici permutabili e diagonalizzabili. *Atti Accad. Pelor. Messina* 37, 299-308.
- 586 DUNCAN, W. J., and A. R. COLLAR: Matrices applied to motions of damped systems. *Phil. Mag.* (7) 19, 197-219.
- 587 FINAN, E. J.: On the number theory of certain non-maximal domains of the total matrix algebra of order 4. *Duke Math. Journ.* 1, 484-490.
- 588 FLOOD, M. M.: Division by non-singular matrix polynomials. *Annals of Math.* (2) 36, 859-869.
- 589 GANTMACHER, F., and M. KRIBIN: Sur les matrices oscillatoires. *Comptes Rendus* 201, 577-579.
- 590 HARRIS, L.: The theory of linear matrix transformations with applications to the theory of linear matrix equations. *Journ. Math. Phys.* 13, 299-420.
- 591 HERRMANN, A.: Lineare Differentialsysteme und Matrixgleichungen. *Proc. Akad. Wet. Amsterdam* 38, 394-401.
- 592 INGRAHAM, M. H., and K. W. WEGNER: The equivalence of pairs of Hermitian matrices. *Trans. Amer. Math. Soc.* 38, 145-162.
- 593 KÖNIG, K.: Über Vektormatrizen II. *Mitt. Math. Ges. Hamburg* 7, 253-258.
- 594 KWAL, B.: Sur la représentation matricielle des quaternions. *Bull. des Sci. Math.* (2) 59, 328-332.
- 595 LAPPO-DANILEVSKIJ, J. A.: Mémoires sur la théorie des systèmes des équations différentielles linéaires II. *Trav. Inst. Phys.-Math. Stekloff* 7, 1-210.
- 596 LEDERMANN, W.: Reduction of singular pencils of matrices. *Proc. Edinb. Math. Soc.* (2) 4, 92-105.
- 597 LITTLEWOOD, D. E.: On induced and compound matrices. *Proc. Lond. Math. Soc.* (2) 40, 370-381.
- 598 MACDUFFEE, C. C., and E. D. JENKINS: A substitute for the Euclid algorithm in algebraic fields. *Annals of Math.* (2) 36, 40-45.
- 599 MCCOY, N. H.: On the rational canonical form of a function of a matrix. *Amer. Journ. Math.* 57, 491-502.
- 600 OLDENBURGER, R.: Canonical triples of bilinear forms. *Tôhoku Math. Journ.* 41, 216-221.
- 601 PARKER, W. V.: The degree of the highest common factors of two polynomials (1934). *Amer. Math. Monthly* 42, 164-166.
- 602 ROMANO, S.: Clebschiano di rette definito da matrice nulla. *Atti Accad. Pelor. Messina* 37, 35-42.
- 603 SCHIEFNER, L. M.: On the m -th power of a matrix. *C. R. Acad. Sci. WRSS* 1, 599-601.
- 604 SCHIEFNER, L. M.: (On the m -th power of a matrix), (Russian with English summary). *Rec. Math. Moscou* 42, 385-394.
- 605 SCHLUCKEBIER, M. L.: Äquimodulare Matrizen. *Diss. Bonn.*
- 606 SCHWERDTFEGER, H.: Sur les fonctions de matrices. *Comptes Rendus* 201, 414-416.
- 607 SEITZ, F.: A matrix-algebraic development of the crystallographic groups II. *Zeits. Kristall. A* 90, 289-313.
- 608 SEITZ, F.: (same title) III. *Zeits. Kristall. A* 91, 336-366.
- 609 SIEGEL, C. L.: Über die analytische Theorie der quadratischen Formen (1934). *Annals of Math.* (2) 36, 527-606.
- 610 TOGNETTI, M.: Sulle matrici permutabili. *R. Accad. Lincei Rend.* (6) 21, 149-196.
- 611 TOGNETTI, M.: Sulla riduzione a forma canonica di una classe speciale di matrici. *Atti Accad. Sci. Torino* 71, 97-104.
- 612 TOSCANO, L.: Una equazione a matrice circolante. *Bull. Un. Mat. Ital.* 14, 293-296.

- 613 TRUMP, P. L.: On a reduction of a matrix by the group of matrices commutative with a given matrix. *Bull. Amer. Math. Soc.* 41, 374-380.
- 614 TURNBULL, H. W.: On the reduction of singular matrix pencils. *Proc. Edinb. Math. Soc.* (2) 4, 67-76.
- 615 TURNBULL, H. W.: On the equivalence of pencils of Hermitian forms. *Proc. Lond. Math. Soc.* (2) 39, 232-248.
- 616 WAZEWSKI, T.: Sur les matrices dont les éléments sont des fonctions continues. *Compositio Math.* 2, 63-68.
- 617 WERJBITZKY, B.: (La convergence absolue des séries potentielles de plusieurs matrices.) (Russian with French summary). *Rec. Math. Moscou* 42, 725-736.
- 618 WERJBITZKY, B.: (La simplification des séries de plusieurs matrices.) (Russian with French summary). *Rec. Math. Moscou* 42, 737-743.
- 619 WHITNEY, H.: On the abstract properties of linear dependence. *Amer. Journ. Math.* 57, 509-533.
- 620 WILLIAMSON, J.: A polar representation of singular matrices. *Bull. Amer. Math. Soc.* 41, 118-123.
- 621 WILLIAMSON, J.: The simultaneous reduction of two matrices to triangle form. *Amer. Journ. Math.* 57, 281-293.
- 622 WILLIAMSON, J.: The equivalence of non-singular pencils of Hermitian matrices in an arbitrary field. *Amer. Journ. Math.* 57, 475-490.
- 623 WITTMAYER, H.: Einfluss der Änderung einer Matrix auf die Lösung des zugehörigen Gleichungssystems, sowie auf die Eigenvektoren. *Diss. Darmstadt* 1935.

1936

- 624 ANDRUETTO, G.: Sul modulo di una matrice. *Rend. R. Ist. Lomb.* (2) 69, 300-308.
- 625 BORUVKA, O.: Sur les matrices singulières. *Comptes Rendus* 203, 600-602, 762.
- 626 BYDZOVSKY, B.: Sur les matrices orthogonales symétriques. *Cas. Mat. Fys.* 65, 189-194.
- 627 CHERUBINO, S.: Fonctions holomorphes de matrice. *Comptes Rendus* 202, 1892-1894.
- 628 CHERUBINO, S.: Sulla riduzione delle matrici a forma canonica. *R. Accad. Lincei Rend.* (6) 23, 478-482, 647-653.
- 629 CHERUBINO, S.: Sulle radici caratteristiche delle funzioni ologomorfe di matrici. *R. Accad. Lincei Rend.* (6) 23, 846-849.
- 630 CHERUBINO, S.: Sulle matrici permutabili con una data. *Rend. Sem. Mat. Padova* 7, 128-156.
- 631 CHERUBINO, S.: Estensione, mediante il calcolo delle matrici, alcuni teoremi sulle omografie degli iperspazi. *Scritti Mat. Off. Luigi Berzolari* 431-437.
- 632 CHERUBINO, S.: Su certe equazioni fondamentali e sul simbolismo delle matrici. *Rend. Sem. Mat. Roma* (4) 1, 96-109.
- 633 CHEVALLEY, C.: L'arithmétique dans les algèbres de matrices. *Actualités Scientifiques et Industrielles.* 323. Paris.
- 634 COMESSATTI, A.: Intorno ad un nuovo carattere delle matrici di Riemann. *Mem. Accad. Ital.* 7, 81-129.
- 635 ECKHART, C., and G. YOUNG: The approximation of one matrix by another of lower rank. *Psychometrika* 1, 211-218.
- 636 FITTING, H.: Über den Zusammenhang zwischen dem Begriff der Gleichartigkeit zweier Ideale und den Äquivalenzbegriff der Elementarteilertheorie. *Math. Annals* 112, 572-582.
- 637 HERRMANN, A.: Remarques sur un théorème de Sylvester. *Enseignement Math.* 34, 332-336.
- 638 KRAUS, F.: Über konvexe Matrixfunktionen. *Math. Zeits.* 41, 18-42.
- 639 LEDERMANN, W.: On singular pencils of Zehfuss, compound, and Schläflian matrices. *Proc. Roy. Soc. Edinb.* 56, 50-89.

- 640 LEDERMANN, W.: The automorphic transformations of a singular matrix pencil. *Quart. Journ. Math.* (2) 7, 277-289.
- 641 MCCOY, N. H.: On the characteristic roots of matrix polynomials. *Bull. Amer. Math. Soc.* 42, 592-600.
- 642 MACDUFFEE, C. C.: A recursion formula for the polynomial solutions of a partial differential equation. *Bull. Amer. Math. Soc.* 42, 244-247.
- 643 MACDUFFEE, C. C.: On a fundamental theorem in matrix theory. *Amer. Journ. Math.* 58, 504-506.
- 644 MOTZKIN, TH.: On vanishing coaxial minors. *Proc. Edinb. Math. Soc.* (2) 4, 210-217.
- 645 PAULI, W.: Contributions mathematiques à la théorie des matrices de Dirac. *Annals Inst. Poincaré*, 6, 109-136.
- 646 RAIFORD, T. E.: Geometry as a basis for canonical forms. *Amer. Math. Monthly* 43, 82-89.
- 647 RICHARDSON, A. R.: Conjugate matrices. *Quart. Journ. Math.* (2) 7, 256-270.
- 648 RINEHART, R. F.: Some properties of the discriminant matrices of a linear associative algebra. *Bull. Amer. Math. Soc.* 42, 570-576.
- 649 ROTH, W. E.: On the characteristic values of the matrix $f(A, B)$. *Trans. Amer. Math. Soc.* 39, 234-243.
- 650 ROTH, W. E.: On k -commutative matrices. *Trans. Amer. Math. Soc.* 39, 483-495.
- 651 SCHIROKOW, P.: (Über den Rand des Wertvorrates der Matrix) (Russian with German summary). *Bull. Soc. Phys.-Math. Kazan* (3) 7, 89-96.
- 652 SCHWERDTFEGGER, H.: Über mehrdeutige Matrixfunktionen. *Compositio Math.* 3, 380-390.
- 653 SEITZ, F.: A matrix-algebraic development of the crystallographic groups IV. *Zeits. Kristall.* A 94, 100-130.
- 654 SPECHT, W.: Zur Theorie der Matrizen. *Jbr. Deutsch. Math. Ver.* 46, 45-50.
- 655 TOSCANO, L.: Sulle potenze di una matrice del secondo ordine. *R. Accad. Lincei Rend.* (6) 23, 493-495.
- 656 TURNBULL, H. W., and J. WILLIAMSON: Hereditary matrices. *Proc. Lond. Math. Soc.* (2) 41, 57-76.
- 657 WILLIAMSON, J.: On the equivalence of two singular matrix pencils. *Proc. Edinb. Math. Soc.* (2) 4, 224-231.
- 658 WILLIAMSON, J.: The idempotent and nilpotent elements of a matrix. *Amer. Journ. Math.* 58, 747-758.
- 659 WEYL, H.: Generalized Riemann matrices and factor sets. *Annals of Math.* (2) 37, 709-745.
- 660 WOLF, L. A.: Similarity of matrices in which the elements are real quaternions. *Bull. Amer. Math. Soc.* 42, 737-743.
- 661 ZIA-UD-DIN, M.: Invariant matrices and S -functions. *Proc. Edinb. Math. Soc.* (2) 5, 43-45.

It is the organization and presentation of the material, however, which make the peculiar appeal of the book. This is no mere compendium of results—the subject has been completely reworked and the proofs recast with the skill and elegance which come only from years of devotion.

—Bulletin of the American Mathematical Society

The very clear and simple presentation gives the reader easy access to the more difficult parts of the theory.

—Jahrbuch über die Fortschritte der Mathematik

In 1937, the theory of matrices was seventy-five years old. However, many results had only recently evolved from special cases to true general theorems. With the publication of his Colloquium Lectures, Wedderburn provided one of the first great syntheses of the subject. Much of the material in the early chapters is now familiar from textbooks on linear algebra. Wedderburn discusses topics such as vectors, bases, adjoints, eigenvalues and the characteristic polynomials, up to and including the properties of Hermitian and orthogonal matrices. Later chapters bring in special results on commuting families of matrices, functions of matrices—including elements of the differential and integral calculus sometimes known as matrix analysis, and transformations of bilinear forms. The final chapter treats associative algebras, culminating with the well-known Wedderburn–Artin theorem that simple algebras are necessarily isomorphic to matrix algebras.

Wedderburn ends with an appendix of historical notes on the development of the theory of matrices, and a bibliography that emphasizes the history of the subject.

ISBN 978-0-8218-4610-0



COLL/17

AMS on the Web
www.ams.org