

Born September 27, 1928, Vienna, Austria

M.S.: 1948, physics, Carnegie Institute of Technology Sc.D.: 1950, Carnegie Institute of Technology

AREA OF INTEREST Partial Differential Equations

POSITIONS Institute for Fluid Dynamics, University of Maryland, 1950-60
 Professor, University of Minnesota, 1961-1998
 Professor Emeritus, University of Minnesota, 1998-
 Head, Department of Mathematics, 1967-69
 Director, Institute for Mathematics and its Applications, 1981-87

VISITING POSITIONS

Visiting Associate Professor, University of Minnesota, 1960
 Visiting Member, Courant Institute of Math. Science, 1966-67
 Visiting Professor, University of Arizona, 1970-71
 Visiting Professor, Stanford University, 1972-73
 Japan Society for the Promotion of Science Fellowship, 1983
 Visiting Professor, University of Maryland Fall 1987
 Visiting Professor, University of California at Los Angeles, Winter 1988
 Visiting Member, MSRI, April, 1988
 Visiting Member, Mathematisches Forschungsinstitut, ETH, Zurich, May 1988
 Visiting Member, Mathematical Institute, University of Oxford, June, 1988

RESEARCH GRANTS

ONR, 1960
 NSF, 1969-70
 NSF, 1971-72
 NSF, 1973-76, Applied Mathematics and Analysis
 NSF, 1976-78, Problems in Partial Differential Equations with Biological and Chemical Applications
 NSF, 1978-84, Analysis of Some Models in Mathematical Biology and Mechanics
 Institute for Mathematics and its Applications: coprincipal investigator of grants from the NSF, AFOSR, ARO, and ONR, 1981-87
 ALCOA Foundation Grant, 1993 and 1994

INVITED DEPARTMENTAL COLLOQUIA (LAST FOUR YEARS)

 Scoula Normale Superiore, Pisa, 1994
 University of Florence, 1994

OFFICES HELD IN PROFESSIONAL SOCIETIES

Society for Industrial and Applied Math Board of Trustees, 1983-88

Member, Section A Steering Committee, American Association for the Advancement of Science 1988-91

Member, Midwest Council, American Academy of Arts and Sciences, 1991-94

EDITORIAL APPOINTMENTS

Archive for Rational Mech. and Anal., 1980-91

Japan J. of Applied Math. 1985 -

SIAM J. on Matrix Analysis and Applications 1987-96

SIAM J. of Anal., 1976-82

Applicable Analysis, 1975-81

Editor, Bull. Amer. Math. Soc. 1974-80

Member, Math. Reviews Editorial Committee 1988 -93

COMMITTEES (NATIONAL AND STATE)

AMS Science Policy Committee, 1978-83

AMS Committee on Russian English Dictionary 1985 - 87

US National Comm. for Math, 1978-81, 84-87

National Research Council , Appl. Math. Panel, 1979-83

NSF Advisory Panel, 1972-75

National Bureau of Standards Applied Math. Panel, 1982-88

University of Wisconsin Mathematics Research Center External Review Committee, 1982

Mathematical Sciences Research Center, Cornell University

External Review Committee 1988

AMS Committee on the 1988 Birkhoff Prize

SIAM Major Awards Committee, 1984-91

Member, Board of Trustees, Mathematical Sciences Research Institute, Berkeley, 1989-94

Site Visit Committee, Fields Institute, Waterloo, Ont., 1991

Panel on new site for the Fields Institute, 1994

External Review Committee, Department of Mathematics, Iowa State University, 1994

MEMBERSHIPS

American Academy of Arts and Sciences

American Mathematical Society

Society for Industrial and Applied Mathematics

Society for Natural Philosophy

GRADUATE DEGREES SUPERVISED

Bert Hubbard, University of Maryland, Ph.D. Thesis: "Bounds for eigenvalues for free and fixed membranes by finite difference methods", 1960

Duane Sather, University of Minnesota, Ph.D. Thesis: "Maximum Properties of Cauchy's Problem in n-Dimensional Space", 1963

John Osborn, University of Minnesota, Ph.D. Thesis:
"Approximation of eigenspaces of a class of unbounded non-self adjoint operators, 1966

Theodore Hatcher, University of Minnesota, Ph.D. Thesis: "A posteriori error bounds for matrix iterative methods of a certain type", 1972
Peter Chang, University of Minnesota, Ph.D. Thesis: "On the breakdown phenomena of solutions of quasi-linear wave equations", 1976
Roger Lui, University of Minnesota, Ph.D. Thesis: "Non-linear integral operators arising from a model in population genetics", 1981
Jianzhong Su, University of Minnesota, Ph. D. Thesis: "Delayed oscillation phenomena in Fitzhugh-Nagumo equation", 1990
Hwei-Ting Lin, University of Minnesota, Ph. D. Thesis: "On the dynamics of a model in the propagation of genes", 1991
Jie Yun, University of Minnesota, Ph. D. Thesis: "Homogenization of a two-region model for the spontaneous combustion of coal stock-piles", 1994

PUBLICATIONS

1. An optimum problem in the Weinstein method for eigenvalues. *Pacific J. Math.* 2 (1952), 413-418.
2. Error estimation in the Weinstein method for eigenvalues. *Proc. Amer. Math. Soc.* 3 (1952), 643-646.
3. An inequality with alternating signs. *Proc. Nat. Acad. Sci.* 38 (1952), 611-613.
4. Upper and lower bounds for torsional rigidity. *J. Math. Phys.* 32 (1953), 54-61.
5. A solution of the singular initial value problem for the Euler-Poisson- Darboux equation. *Proc. Amer. Math. Soc.* 4 (1953), 703-715. (with J.B. Diaz)
6. Free vibrations of constrained beams (discussion of a paper of W.F.Z. Lee and E. Saibel). *J. Appl. Mech.* 20 (1953), 310.
7. Stability of thin elastic plates (discussion of a paper of G.A. Zizicas). *J. Appl. Mech.* 20 (1953), 592. (with A. Weinstein)
8. Sur les solutions fortes du probleme de Tricomi. *C.R. Paris* 238 (1954), 1961-1962.
9. An extension of the classical Sturm-Liouville theory. *Duke Math. J.* 22 (1955), 1-14.
10. New bounds in harmonic and biharmonic problems. *J. Math. Phys.* 33 (1955), 291-307. (with L.E. Payne)
11. Sur le quotient de deux frequences propres consecutives. *C.R. Paris* 241 (1955), 917-919. (with L.E. Payne and G. Polya)
12. An isoperimetric inequality for the N-dimensional free membrane problem. *J. Rat. Mech.* 5 (1956), 633-636.
13. Upper and lower bounds for eigenvalues by finite difference methods. *Comm. Pure Appl. Math.* 9 (1956), 613-623.
14. A maximum property of Cauchy's problem. *Ann. Math.* 64 (1956), 505-513.
15. On the ratio of consecutive eigenvalues. *J. Math. Phys.* 35 (1956), 289- 298. (with L.E. Payne and G. Polya)

16. Remark on a paper of O.G. Owens. *Duke Math. J.* 24 (1957), 233-234. (with L.E. Payne).
17. Note on a lemma of Finn and Gilbarg. *Acta Math.* 98 (1957), 297-299. (with L.E. Payne)
18. A variational computation method for forced-vibration problems. *Proc. Symp. on the Calculus of Variations and its Applications*, Chicago, 1957, 89-91.
19. Lower bounds for vibration frequencies of elastically supported membranes and plates. *J. Soc. Ind. Appl. Math.* 5 (1957), 171-182. (with L.E. Payne)
20. Remarks on the preceding paper of Lax. *Comm. Pure Appl. Math.* 11 (1958), 195-196.
21. Lower bounds for higher eigenvalues by finite difference methods. *Pacific J. Math.* 8 (1958), 339-368.
22. New bounds for solutions of second order elliptic partial differential equations. *Pacific J. Math.* 8 (1958), 551-573. (with L.E. Payne)
23. Optimal approximation and error bounds. *Proc. Symp. on Numerical Approximation*, Univ. of Wis. Press, 1959, 117-190. (with M. Golomb)
24. Error bounds in finite difference approximation to solutions of symmetric hyperbolic systems. *J. Soc. Ind. Appl. Math.* 7 (1959), 49-75.
25. Exact bounds for solutions of hyperbolic equations by finite difference methods. *Proc. Symp. on Numerical Treatment of Partial Differential Equations with Real Characteristics*, Rome, 1959, 87-97.
26. An optimal Poincare inequality for convex domains. *Arch. Rat. Mech. Anal.* 5 (1960), 182-188. (with L.E. Payne)
27. Error bounds in the Rayleigh-Ritz approximation of eigenvectors. *Nat. Bureau of Standards J. of Research* 64B (1960), 216-225.
28. A maximum property of Cauchy's problem in three-dimensional space-time. *Proc. Symp. on Partial Differential Equations*, Berkeley, 1960, 91-99.
29. Optimal approximation for functions prescribed at equally spaced points. *Nat. Bureau of Standards J. of Research* 65B (1961), 99-104.
30. On Korn's inequality. *Arch. Rat. Mech. Anal.* 8 (1961), 89-98. (with L.E. Payne)
31. Some isoperimetric inequalities for membrane frequencies and torsional rigidity. *J. Math. Anal. Appl.* 2 (1961), 210-216. (with L.E. Payne)
32. Symmetrization in uniformly elliptic problems. *Stud. in Math. Anal. and Related Topics*, Stanford Univ. Press, 1962, 424-428.
33. Regular points for elliptic equations with discontinuous coefficients. *Ann. Scuola Norm. Sup. Pisa* 17 (1963), 45-79. (with W. Littman and G. Stampacchia)
34. An effectless cutting of a vibrating membrane. *Pacific J. Math.* 13 (1963), 1239-1240.
35. On bounding harmonic functions by linear interpolation. *Bull. Amer. Math. Soc.* 70 (1964), 525-529.
36. Bounds for solutions of second order elliptic equations in terms of arbitrary vector fields. *Arch. Rational Mech. Anal.* 20 (1965), 95-106. (with L. E. Payne)
37. Isolated singularities of linear elliptic equations. *Amer. J. Math.* 88 (1966), 258-272. (with J.B. Serrin)
38. On the capacity of composite conductors. *J. Math. Phys.* 44 (1965), 375-383. (with M.H. Protter)

39. On the spectrum of general second order operators. *Bull. Amer. Math. Soc.* 72 (1966), 251-255. (with M.H. Protter)
40. A posteriori error bounds in iterative matrix inversion. *Proc. Symp. on Numerical Treatment of Partial Differential Equations*, Maryland, 1965.
41. On a nonlinear eigenvalue problem. *J. Math. Anal. Appl.* 21 (1968), 506-509.
42. Exchange of stability in Couette flow. In *Bifurcation Theory and Nonlinear Eigenvalue Problems* (ed. Joseph B. Keller and Stuart Antman), Benjamin, New York, 1969, pp. 395-409.
43. Curvature inequalities for surfaces over a disk. In *Some Problems of Mathematics and Mechanics* (M.A. Lavrentieff Anniversary Volume), Siberian Branch of the Akademia Nauk USSR, 1971, 242-250, *Amer. Math. Soc. Transl.* 104 (1976), 223-231. (with J. Serrin)
44. Remark on the preceding paper of Serrin. *Arch. Rat. Mech. Anal.* 43 (1971), 369-370.
45. Variational properties of steady fall in Stokes flow. *J. Fluid Mech.* 52 (1972), 321-344.
46. On optimal numerical solutions of partial differential equations. *SIAM J. Numer. Anal.* 9 (1972), 182-198.
47. On the steady fall of a body in a Navier-Stokes fluid. *Proc. Symp. Pure Math.*, Amer. Math. Soc., Providence, 23 (1973), 421-439.
48. Asymptotic properties of Leray's solution of the stationary two-dimensional Navier-Stokes equation. *Uspekhi Mat. Nauk* 29 (1974), 109-122. (with D. Gilbarg)
49. A maximum principle and gradient bounds for linear elliptic equations. *Indiana Math. J.* 23 (1973), 239-249. (with M.H. Protter)
50. Variational principles for a body falling in steady Stokes flow. *Symp. on Continuum Mechanics and Related Problems in Analysis*. Izdat. Metsniereva, Tbilisi, 1974, 330-339.
51. Variational inequalities for a viscous shearing flow. *J. Fluid Mech.* 68 (1975), 739-755. (with A. Nir and A. Acrivos)
52. Invariant sets for weakly coupled parabolic and elliptic systems. *Rend. di Mat. Ser. VI* 8 (1975), 295-310.
53. Nonlinear diffusion in population genetics, combustion, and nerve propagation. *Proc. Tulane Program in Partial Differential Equations, Lecture Notes in Math.* #446, Springer, New York, 1975, 5-49. (with D.G. Aronson)
54. Multidimensional nonlinear diffusion arising in population genetics. *Adv. in Math.* 30 (1978), 33-76. (with D.G. Aronson)
55. The stability of bifurcating solutions. *Nonlinear Analysis*, ed., L. Cesari, R. Kannan, and H.F. Weinberger, Academic Press, New York, 1978, 219-233.
56. The stability of solutions bifurcating from steady or periodic solutions. *Dynamical Systems*, ed., A.R. Bednarek and L. Cesari, Acad. Press, New York, 1977, pp. 349-366.
57. Optimal shapes for brittle beams under torsion. *Complex Analysis and its Applications*, a volume in honor of I.N. Vekua, Steklov Institute, Moscow, 1978, 88-91. (with J.B. Serrin)
58. Asymptotic behavior of a model in population genetics. *Nonlinear Partial Differential Equations*, ed., J.M. Chadam, *Lecture Notes in Math.* 648, Springer, New York, 1978,

- 47-96.
59. Asymptotic properties of steady plane solutions of the Navier-Stokes equations with bounded Dirichlet integrals. *Ann. Scuola Norm. Pisa (IV)* 5 (1978), pp. 381-404. (with D. Gilbarg)
 60. Some remarks on good, simple, and optimal quadrature formulas. *Recent Advances in Numerical Analysis*, ed., C. de Boor and G.H. Golub, Academic Press, New York, 1978, 207-229.
 61. Asymptotic behavior of a class of discrete-time models in population genetics. *Applied Nonlinear Analysis*, Academic Press, New York, 1979, 407-422.
 62. Genetic wave propagation, convex sets, and semi-infinite programming. *Constructive Approaches to Mathematical Models*, ed., C.V. Coffman and G.J. Fix, Academic Press, New York, 1979, 293-317.
 63. Spatial patterning of the spruce budworm. *J. of Math. Biology*, 8 (1979), 217-258. (with D. Ludwig and D.G. Aronson)
 64. Some deterministic models for the spread of genetic and other alterations. *Models of Biological Growth and Spread - Mathematical Theories and Applications*, W. Jäger, H. Rost, and P. Tautu, eds., *Lecture Notes in Biomathematics*, Springer, 1980, pp. 320-349.
 65. Long-time behavior of a class of biological models. *SIAM J. on Math. Anal.* 3 (1982), 353-396.
 66. Norm-preserving dilations and their applications to optimal error bounds. *SIAM J. on Numerical Anal.* 19 (1982), 445-469. (with C. Davis and W.M. Kahan)
 67. Forgotten parameters and catastrophic behavior in a stochastic buckling problem. *Dynamical Systems II*, ed. A. R. Bednarek and L. Cesari, Academic Press, 1982, pp. 447-497. (with S. Rosenblat)
 68. A characterization of the Polya frequency function of order 3. *Applicable Anal.* 15 (1983), 53-69.
 69. Optimal numerical approximation of a linear operator. *Linear Alg. and its Appl.* 52/53 (1983), 717-737.
 70. A simple system with a continuum of stable inhomogeneous steady states. *Nonlinear Partial Differential Equations in Applied Science; Proceedings of the US - Japan Seminar, Tokyo, 1982*, H. Fujita, P.D. Lax, and G. Strang, eds. *Lecture Notes in Num. and Appl. Anal.* #5, Kinokuniya, Tokyo/North Holland, Amsterdam 1983, 345-359.
 71. The spatial homogeneity of stable equilibria of some reaction-diffusion systems on convex domains. *J. of Diff. Eq.* 58 (1985), 15-21 (with K. Kishimoto)
 72. Inequalities between Dirichlet and Neumann eigenvalues. *Archive for Rat. Mech. and Anal.* 94 (1986), 193-208 (with H. Levine)
 73. On metastable patterns for parabolic systems. *Atti dei Convegni Lincei 77, Convegno Celebrativo del Centenario della Nascita di Mauro Picone e di Leonida Tonelli. Accad. Naz dei Lincei, Rome, 1986.*
 74. A density-dependent diffusion system with stable discontinuous stationary solutions. *Annali di Mat. Pura ed Applicata (IV)* 152 (1988), 259- 280 (with D.G. Aronson and A. Tesei)
 75. Some remarks on invariant sets for systems. In *Maximum Principles and Eigenvalue*

- Problems in Partial Differential Equations, ed. P.W. Schaefer. Pitman Research Notes in Mathematics 175, Longman, 1988, pp. 189-207.
76. Conditions for a local Pareto optimum. Preferences, Uncertainty, and Optimality, ed. J.S. Chipman, D.McFadden, and M.K. Richter. Westview Press, Boulder, 1990, pp. 56-67.
 77. Convergence to spatial-temporal clines in the Fisher equation with time-periodic fitnesses. *J. of Mathematical Biology* 28 (1990), pp. 83-98. (with Peter Hess)
 78. Long-time behavior for a regularized scalar conservation law in the absence of genuine nonlinearity. *Annales de l'Institut Henri Poincare, Analyse Non Lineaire* 7 (1990), pp. 407-425
 79. A necessary condition for decentralization and an application to intertemporal allocation. *Journal of Economic Theory* 51 (1990), pp. 313 -345. (with L. Hurwicz)
 80. A stochastic model of latent image formation. 11th International Conf. of Differential Equations, Dundee, 1990. (with D. Sattinger)
 81. Dualizing the Poisson summation formula. *Proc. National Acad of Sci.* 88(1991), pp. 7348-7350. (with R.J.Duffin)
 82. On a backward-forward parabolic equation. *J. of Differential Equations*, 105 (1993) 264-295 (with M. Freidlin)
 83. Degenerate elliptic models for perfectly plastic flows. in *Elliptic and Parabolic Problems*, Pont-á-Mousson, 1994, ed. Bandle, Bemelmans, Chipot, Paulin, and Shafrir, Pitman Research Notes in Mathematics #325, Longman, 1995, pp. 240-250.
 84. Some mathematical aspects of buckling. in *Summation Theorems in Structural Stability*, ed. T. Tarnai. CISM, International Centre for Mechanical Sciences #354, Springer, 1995, pp. 1-37.
 85. A note on the optimal state of a binary solid mixture in a stressed elastic bar. *Mechanica* 31 (1996), pp. 519-525 (with R. Fosdick and G. F. Royer-Carfagni)
 86. The minimum energy configuration of a mixed-material column. in *Partial Differential Equations and Applications*, ed, P. Marcellini, G. Talenti, and E. Vesentini, Dekker, 1996, pp. 347-351.
 87. On optimal extrusion dies for rigid-plastic materials. *Quarterly of Applied Mathematics* 56 (1998), pp. 543-552.
 88. Approximability by weighted norms of the structured and volumetric singular values of a class of nonnegative matrices. *SIAM J. of Matrix Analysis and Applications* 18 (1997), pp. 249-257 (with Daniel Hershkowitz, Wenchao Huang, and Hans Schneider.)
 89. On the nonexistence of certain ideal forming operations for extrusion and drawing dies. *J. of Mech. and Phys. of Solids* 45 (1997), pp. 1275-1280.
 90. On matrices for which norm bounds are attained. *vLinear Analysis and Applications* 275/276 (1998), pp. 563-577. (with Hans Schneider.)
 91. On Dualizing a Multivariable Poisson Summation Formula. *Journal of Fourier Analysis and Applications* 3 (1997), pp. 487-497. (with R. J. Duffin)
 92. Boundary and initial boundary-value problems for separable backward-forward parabolic problems. *Journal of Mathematical Physics* 38 (1997), pp. 4343-4353. (with J. B. Keller)

93. On optimizing extrusion dies for rigid-plastic materials. *Nova Journal of Mathematics, Game Theory, and Algebra* 6 (1997), pp. 215-221.
94. An example of blowup produced by equal diffusions. *J. of Diff. Equations* 154 (1999), pp. 225-237.
95. Fichera's method for bounding eigenvalues. in *Interactions Between Analysis and Mechanics - the Legacy of Gaetano Fichera*. *Atti dei Convegni Lincei* 148, *Accad. Naz. dei Lincei*, Rome, 1999, pp.51-65.
96. An extension of Fichera's eigenvalue bounds to the Neumann problem. in *Homage to Gaetano Fichera*, ed. A.Cialdea, *Quaderni di Matematica* 7, *Aracne*, Rome 2000, pp. 335-347.
97. Analysis of the linear conjecture for spread in cooperative models. *Journal of Mathematical Biology* 45 (2002), pp. 183-218. (with Mark A. Lewis and Bingtuan Li)
98. Spreading speed and the linear conjecture for two-species competition models. *Journal of Mathematical Biology* 45 (2002), pp. 219-233. (with Mark A. Lewis and Bingtuan Li)
99. On spreading speeds and traveling waves for growth and migration models in a periodic habitat. *Journal of Mathematical Biology* 45 (2002), pp. 511-548.
100. Pest control may make the pest population explode. *Zeitschrift für Angewandte Mathematik un Physik* 54 (2003), pp. 869-873. (with Hirokazu Ninomiya)
101. Inward linear perturbation can produce unbounded solutions. *Mathematical Methods in the Applied Sciences* 27 (2004), pp. 1815-1818. (with Hirokazu Ninomiya)
102. Spreading speeds as slowest wave speeds for cooperative systems, *Math. Biosc.* 196 (2005), pp. 82-98. (with Bingtuan Li and Mark A. Lewis)
103. On p -homogeneous systems of differential equations and their linear perturbations. *Applicable Analysis* 85 (2006), pp. 225-247. (with Hirokazu Ninomiya)
104. Anomalous spreading speeds in cooperative recursion systems. *J. of Math. Biol.* 55 (2007) pp. 207-222. (with Mark A. Lewis and Bingtuan Li)
105. Spreading speeds of spatially periodic integro-difference models for populations with non-monotone recruitment functions. *J. of Math. Biol.* 57 (2008), pp. 387-411. (with K. Kawasaki and N. Shigesada)
106. Existence of traveling waves for integral recursions with nonmonotone growth functions. *J. of Math. Biol.* 58 (2009) pp. 323-338. (with Bingtuan Li and Mark A. Lewis)
107. Spreading speeds for a partially cooperative 2-species reaction-diffusion model. *Discrete and Continuous Dynamical Systems A* 23 (2009) pp. 1087-1098. (with K. Kawasaki and N. Shigesada)

Books

A First Course in Partial Differential Equations, Dover, 1995.
 Maximum Principles in Differential Equations, Prentice-Hall, Englewood Cliffs, New Jersey, 1967; Springer, New York, 1985. (with M. H. Protter).
 Variational Methods for Eigenvalue Approximation, C.B.M.S. Regional Conference Series in Applied Mathematics #15, S.I.A.M., Philadelphia, 1974.