

Dr. John Andraos

CareerChem, 504-1129 Don Mills Road, Don Mills, Ontario M3B 2W4 Canada

E-mail: c1000@careerchem.com

Webpage: <http://www.careerchem.com/MainFrame.html>

EDUCATION

Ph.D., University of Toronto; Physical Organic Chemistry 1992
B.Sc., University of Toronto; Biochemistry 1987

PROFESSIONAL EXPERIENCE

Founder of *CareerChem*, National Directory of Departments of
Chemistry in Canada website 2000 – present
Green chemistry book author, Taylor & Francis, CRC Press 2007 – present
Consultant for pharmaceutical industry 2007 – present
(Merck & Co., NJ; Row2 Technologies, NJ)
Course Director and Lecturer, York University, Canada 1999 – 2009
Visiting Scholar, University of Toronto, Canada 1997 – 1998
Junior Research Fellow, The University of Queensland, Australia 1995 – 1997
NSERC Post-doctoral Fellow, University of Ottawa, Canada 1992 – 1994

PROFESSIONAL AND SCHOLASTIC HONOURS

President, SigmaXi University of Toronto Chapter 2004 – 2006
2013 – 2016
Australian Research Council (ARC) Junior Research Award, 1996
[University of Queensland](#)
University of Queensland Post-doctoral Fellowship 1995 - 1997
NSERC Post-doctoral Fellow, University of Ottawa 1993 - 1994
NSERC Undergraduate Student Research Award, University of
Toronto, *Tenured in the laboratory of Prof. J. Bryan Jones* 1986
F.E. Beamish Prize in Chemistry, University of Toronto 1985 - 1986
Mary H. Beatty Admission Scholarship, University of Toronto 1983 - 1986
Ontario Youth Medal 1985

INVITED ADDRESSES

Effective Visualization Exercises for Teaching Organic Chemistry, Chemistry Instructor
Workshop, University of Toronto, Canada (2013)
Future Leaders in Green Chemistry Workshop and Challenge, University of Toronto, Canada
(2013)
University of Toronto, Toronto, Canada (2011)
University of Ontario Institute of Technology, Oshawa, Canada (2010)
University of Toronto, Toronto, Canada, (2009)
Apotex Pharmachem, Inc., Brantford, Canada (2008)
15th International Conference on Organic Process Research and Development, San Diego,
California, USA (2007)

BioVerdant, Inc., San Diego, California, USA (2007)

Three-day training course given by Scientific Update LLP, Le Centre Sheraton, Montreal, Canada (2007)

Merck & Co., Rahway, NJ, USA (2007)

University of Toronto, Toronto, Canada, Sigma-Xi Distinguished Lecture Series (2007)

CIC Chair's Event: Diversity in Chemical Careers Panel Discussion, CSC Conference and Exhibition 2006, Halifax, Nova Scotia, Canada (2006)

Green Chemistry and Engineering Education Workshop, Chemical Sciences Roundtable, National Academies, Washington, D.C., USA (2005)

Concordia University, 6th Chemistry and Biochemistry Graduate Research Conference, Montreal, Canada, (2003)

PROFESSIONAL TEACHING EXPERIENCE

York University and University of Toronto

1999 - 2009

Departments of Chemistry, Toronto, CANADA
Course Director and Lecturer

Lectured honours undergraduate and graduate level courses in mechanistic, synthetic organic, and industrial chemistry (**CHEM 3021/3070/4023/5030** at York, **CHM 1045** at U Toronto) covering topics in organic synthesis, environmental ("green") chemistry methods, industrial process chemistry, reaction optimization, mathematics of kinetic systems, linear free energy relationships, proton transfer reactions, isotope effects, and reaction intermediates

PROFESSIONAL RESEARCH EXPERIENCE

York University

2000 - 2009

Department of Chemistry, Toronto, CANADA
Research Scientist

- Application of reaction metrics for analysis of organic reactions and total syntheses of organic molecules; optimization of recycling and reagent retrieval protocols; discovery of new multi-component reactions by structural combinatorial techniques; unified mathematical analysis of green metrics; molecular complexity
- Quantification and optimization of dynamic kinetic resolution relevant to stereoselective syntheses of pharmaceuticals and sedatives (thalidomide); advanced mathematical analysis; analytical and numerical solution of systems of differential equations encountered in kinetics problems in homogeneous and heterogeneous chemical systems
- Dynamic NMR studies on novel phthalocyanines relevant to photodynamic therapy and materials science; with **Prof. Cliff Leznoff**
- Development of pedagogical exercises and computer software for 3-D visualization of molecules relevant to the teaching of stereochemistry to undergraduates in years 2 and 3; with **Prof. Walter Whiteley**, Department of Mathematics and Statistics

University of Toronto

1997 - 2000

Departments of Chemistry, Toronto, CANADA
Visiting Scientist

Kinetic investigation of complex chemical systems in solution and in heterogeneous media

- Unified kinetic methodologies for describing complex kinetic behaviour in matrices, polymers, zeolites, and other restricted media including Kohlrausch-Williams-Watts, Albery-

Siebrand, exponential series method (ESM), and maximum entropy method (MEM) analyses.

The University of Queensland

1995 - 1997

Department of Chemistry, Brisbane, AUSTRALIA

Junior Staff Researcher: (with Professor C. Wentrup)

Mechanistic studies of novel thermolytic and photolytic rearrangements of cumulenes by matrix isolation FT-IR spectroscopy and variable temperature NMR.

- Awarded an \$18,000 Australian Research Council grant for Junior Researchers.
- Developed methods of implementing heterogeneous phase reaction modelling techniques involving time-dependent rate constants and distribution analysis using commercially available software packages.
- Discovery of novel heterocumulenes by pyrolysis and photolysis of heterocyclic compounds and study by low temperature FT-IR matrix isolation spectroscopy

University of Ottawa

1993 - 1994

Department of Chemistry, Ottawa, CANADA

NSERC Post-doctoral Fellow: (with Professor J.C. Scaiano)

Mechanistic studies of photochemical reactions by time-resolved laser flash photolysis in solution and in zeolites.

- Developed a GC/MS protocol for the elucidation of reaction mechanism for photoacid generation from sulfonic acid derivatives (with Shipley Co.)
- Developed computational methods for treatment of kinetic data of photochemical reactions in heterogeneous media; generalization of calculation protocols

University of Toronto

1987 - 1992

Department of Chemistry, Toronto, CANADA

Graduate Student and Teaching Assistant: (with Professor A.J. Kresge - deceased)

Investigation of ketene hydration reaction mechanism in aqueous solution by time-resolved flash photolysis and *ab initio* computational methodologies.

- Built and designed \$200,000 laser flash photolysis facility at the University of Toronto shared among 3 research groups with a total of 12 personnel.

Universität Basel

1991

Institut für Physikalische Chemie, Basel, SWITZERLAND

Visiting Doctoral Student: (with Professor Jakob Wirz)

PROFESSIONAL AFFILIATIONS

Canadian Society of Chemistry (CSC, 1988 -)

American Chemical Society (ACS, 1988 -)

Inter-American Photochemical Society (IAPS, 1993 -)

Mathematical Association of America (MAA, 1993 -)

Royal Canadian Institute for the Advancement of Science (RCI, 1997 -)

Sigma-Xi (1999 -)

Reviewer for *Journal of the American Chemical Society*, *Journal of Organic Chemistry*, *Organic Letters*, *Journal of Physical Organic Chemistry*, *Journal of Chemical Education*, *Journal of Theoretical Biology*

Editorial Board Member: *The Open Current Process Chemistry Journal*, *Current Green Chemistry*

Executive Board member (2001 – 2017), *Sigma-Xi University of Toronto Chapter*
Member of Faculty of Pure and Applied Science Council, York University (2002 - 2009)

PUBLICATIONS AND CONTRIBUTIONS

(A) Books and Book Chapters

A. Hent, J. Andraos, *Solutions to Advanced Organic Reaction Mechanisms: A New Perspective on McKillop's Problems*, Elsevier, London: 2019.

J. Andraos, *Reaction Green Metrics – Problems, Exercises, and Solutions*, CRC Press-Taylor & Francis: Boca Raton, 2019.

J. Andraos, *Synthesis Green Metrics – Problems, Exercises, and Solutions*, CRC Press-Taylor & Francis: Boca Raton, 2019.

J. Andraos, Application of Step, Cumulative, and Global E-factor and PMI Metrics to Gauge Synthesis Efficiency: L-DOPA and Apixaban Pharmaceutical Examples in *Green Synthetic Processes and Procedures*, (R. Ballini, ed.), Royal Chemical Society: United Kingdom, 2019, Chapter 3, pp. 39-52.

J. Andraos and A. Hent, Key Metrics to Inform Chemical Synthesis Route Design in *Handbook of Green Chemistry, Volume 11*, (D.J.C. Constable, C. Jiménez-González, eds.), Wiley-VCH, 2018, Chapter 3, pp. 49-94.

J. Andraos, Application of Green Metrics Analysis to the Synthesis of Dicyclohexylcarbodiimide (DCC) – comparison of chlorine versus non-chlorine based routes in *Chemistry Beyond Chlorine*, (P. Tundo, L.N. He, E. Lokteva, C. Mota, eds.), Springer-Verlag, 2016, Chapter 22, pp. 587 – 604.

J. Andraos and A.P. Dicks, The State of Green Chemistry Instruction at Canadian Universities in *Worldwide Trends in Green Chemistry Education*, (V. Zuin, L. Mammino, eds.), Royal Society of Chemistry, 2015, Chapter 11, pp. 179 – 212.

P. Tundo and **J. Andraos** (eds.), *Green Syntheses Volume 1*, CRC Press-Taylor & Francis: Boca Raton, 2014.

J. Andraos*, Application of Green Metrics to Scalable Industrial Synthesis Plans: An Update on Syntheses of Oseltamivir Phosphate (Tamiflu) in *Scalable Green Chemistry: Case Studies from the Pharmaceutical Industry*, (S.G. Koenig, ed.), Pan Stanford Publishing: 2013, Chapter 4, pp. 75 – 104.

J. Andraos*, Green Chemistry Metrics: Material Efficiency and Strategic Synthesis Design in *Innovations in Green Chemistry and Green Engineering*, (P.T. Anastas, J.B. Zimmerman, eds.), Springer: New York, 2013, Chapter 4, pp. 81 – 113.

J. Andraos*, *The Algebra of Organic Synthesis: Green Metrics, Design Strategy, Route Selection, and Optimization*, CRC Press-Taylor & Francis: Boca Raton, 2012.

J. Andraos*, Designing a Green Organic Chemistry Lecture Course in *Green Organic Chemistry in Lecture and Laboratory*, (A.P. Dicks, ed.), CRC Press-Taylor & Francis: Boca Raton, 2012, Chapter 2, pp. 29 – 68.

J. Andraos*, Parameterization and Tracking of Optimization of Synthesis Strategy Using Computer Spreadsheet Algorithms in *Handbook of Green Chemistry, Volume 7 – Green Processes* (P.T. Anastas, C.J. Li, eds.), Wiley-VCH: Weinheim, 2012, Chapter 13.

J. Andraos*, Green Chemistry Metrics: Material Efficiency and Strategic Synthesis Design in *Encyclopedia of Sustainability Science and Technology*, (P.T. Anastas, J. Zimmerman, eds.), Springer-Verlag: New York, 2011.

J. Andraos*, Application of Green Metrics Analysis to Chemical Reactions and Synthesis Plans, in *Green Chemistry Metrics*, (Alexei Lapkin, David C. Constable, eds.), Blackwell Scientific: Oxford, 2008, Chapter 4, pp. 69 – 199.

J. Andraos*, Atom Economy, Reaction Mass Efficiency, and E-factor Green Metrics for Gauging Material Efficiencies of Reactions and Synthesis Plans: Paradigms and Examples in *Handbook of Green Chemistry*, (W.M. Nelson, ed.), Oxford University Press: New York, accepted. [Note: This book has been withdrawn from Oxford University Press]

(B) Refereed Publications

70 publications in peer-reviewed journals

70. J. Andraos*, A Proposed Sustainability Index for Synthesis Plans Based on Input Provenance and Output Fate: Application to Academic and Industrial Synthesis Plans for Vanillin as a Case Study, *Beilstein J. Org. Chem.* **2020**, 16, 2346-2362. doi:10.3762/bjoc.16.196 ([open access article](#))

69. J. Andraos*, Aiming for a Standardized Protocol for Preparing a Process Green Synthesis Report and for Ranking Multiple Synthesis Plans to a Common Target Product, *Green Processing & Synthesis* **2019**, 8, 787-801. doi:10.1515/gps-2019-0048 ([open access article](#))

68. J. Andraos*, The Principle of Conservation of Structural Aspect: Facilitating Visual Communication and Learning in Organic Chemistry Instruction, *ChemRxiv* **2019**, doi:10.26434/chemrxiv.8144075

67. J. Andraos*, Aiming for a Standardized Protocol for Preparing a Process Green Synthesis Report and for Ranking Multiple Synthesis Plans to a Common Target Product, *ChemRxiv* **2019**, doi:10.26434/chemrxiv.7931966

66. J. Andraos*, Evaluation of Industrial Routes to Vinyl Chloride According to Material and Energy Efficiency Metrics Analysis, *ChemRxiv* **2019**, doi:10.26434/chemrxiv.7688183

65. J. Andraos*, Solution to an Unsolved Sangaku Geometry Puzzle, <http://www.careerchem.com/MATH/Solution to an Unsolved Sangaku Geometric Puzzle-v6b.pdf>

64. J. Andraos*, Relationships Between Step and Cumulative PMI and E-factors: Implications on Estimating Material Efficiency With Respect to Charting Synthesis Optimization Strategies, *Green Processing & Synthesis* **2019**, 8, 324-336. doi:10.1515/gps-2018-0131 ([open access article](#))

63. J. Andraos*, A Master Class in Dimensional Analysis: the Universal Gas Constant, *ChemRxiv* **2018**, doi:10.26434/chemrxiv.6874886

62. J. Andraos*, Relationships Between Step and Cumulative PMI and E-factors: Implications on Estimating Material Efficiency With Respect to Charting Synthesis Optimization Strategies, *ChemRxiv* **2018**, doi:10.26434/chemrxiv.6686729.v1

- 61.** Musolino, M.; **Andraos, J.**; Aricò, F.*; An Easy Scalable Approach to HMF Employing DMC as Reaction Media: Reaction Optimization and Comparative Environmental Assessment, *ChemSelect* **2018**, *3*, 2359-2365. doi:10.1002/slct.201800198
- 60.** **J. Andraos***, Useful Tools for the Next Quarter Century of Green Chemistry Practice – A Dictionary of Terms and a Dataset of Parameters for High Value Industrial Commodity Chemicals, *ACS Sust. Chem. Eng.* **2018**, *6*, 3206-3214. doi:10.1021/acssuschemeng.7b03360 (invited paper)
- 59.** **J. Andraos***, A New Paradigm for Designing Ring Construction Strategies for Green Organic Synthesis: Implications for the Discovery of Multi-Component Reactions to Build Molecules Containing a Single Ring, *Beilstein J. Org. Chem.* **2016**, *12*, 2420-2442. doi:10.3762/bjoc.12.236 (invited paper)
- 58.** **J. Andraos***, Using Balancing Chemical Equations as a Key Starting Point to Create Green Chemistry Exercises Based on *Inorganic Syntheses* Examples, *J. Chem. Educ.* **2016**, *93*, 1330-1334. doi:10.1021/acs.jchemed.5b00770
- 57.** **J. Andraos***; Mastronardi, M.L.; Hoch, L.B.; Hent, A. Critical Evaluation of Published Algorithms for Determining Environmental and Hazard Impact Green Metrics of Chemical Reactions and Synthesis Plans, *ACS Sust. Chem. Eng.*, **2016**, *4*, 1934-1945. doi:10.1021/acssuschemeng.5b01555 (ACS Authors Choice open access article)
- 56.** **J. Andraos***, Critical Evaluation of Published Algorithms for Determining Material Efficiency Green Metrics of Chemical Reactions and Synthesis Plans, *ACS Sust. Chem. Eng.*, **2016**, *4*, 1917-1933. doi:10.1021/acssuschemeng.5b01554
- 55.** **J. Andraos***, A Complete Green Metrics Evaluation of Various Routes to Methyl Methacrylate According to Material and Energy Consumptions, and Environmental and Safety Impacts: A Test Case from the Chemical Industry, *ACS Sust. Chem. Eng.*, **2016**, *4*, 312-323. doi:10.1021/acssuschemeng.5b01240
- 54.** **J. Andraos***; A. Hent, "Simplified application of material efficiency green metrics to synthesis plans: pedagogical case studies selected from *Organic Syntheses*", *J. Chem. Educ.* **2015**, *92*, 1820-1830. doi:10.1021/acs.jchemed.5b00058
- 53.** **J. Andraos***; A. Hent, "Useful material efficiency green metrics problem set exercises for lecture and laboratory", *J. Chem. Educ.* **2015**, *92*, 1831-1839. doi:10.1021/acs.jchemed.5b00059
- 52.** **J. Andraos***; E. Ballerini; L. Vaccaro*, "A Comparative Approach to the Most Sustainable Protocol for the β -Azidation of α,β -Unsaturated Ketones and Acids", *Green Chem.* **2015**, *17*, 913-925. doi:10.1039/C4GC01282H
- 51.** A.D. Allen; **J. Andraos**; T.T. Tidwell*, S. Vukovic, "Ketene Reactions with Tertiary Amines", *J. Org. Chem.* **2014**, *79*, 679-685. doi:10.1021/jo402438w
- 50.** **J. Andraos***, On the Probability that Ring-forming Multicomponent Reactions are Intrinsically Green: Setting Thresholds for Intrinsic Greenness Based on Design Strategy and Experimental Reaction Performance, *ACS Sust. Chem. Eng.* **2013**, *1*, 496-512. doi:10.1021/sc3001614
- 49.** **J. Andraos***, Safety-Hazard Indices: Completion of a Unified Suite of Metrics for the Assessment of "Greenness" for Chemical Reactions and Synthesis Plans, *Org. Process Res. Develop.* **2013**, *17*, 175-192. doi:10.1021/op300352w
- 48.** **J. Andraos***, Inclusion of Environmental Impact Parameters in Radial Pentagon Material Efficiency Metrics Analysis: Using Benign Indices as a Step Towards a Complete Assessment

of "Greenness" for Chemical Reactions and Synthesis Plans, *Org. Process Res. Develop.* **2012**, 16, 1482-1506. doi:10.1021/op3001405

47. J. Andraos*; A.P. Dicks*, Green Chemistry Teaching in Higher Education: A Review of Effective Practices, *Chem. Educ. Res. Pract.*, **2012**, 13, 69-79. doi:10.1039/C1RP90065J (invited paper)

46. J. Andraos*, A Green Metrics Assessment of Phosgene and Phosgene-free Syntheses of Industrially Important Commodity Chemicals, *Pure Applied Chem.* **2012**, 84, 827-860. doi:10.1351/PAC-CON-11-06-12 (invited paper)

45. S.M. Mercer; **J. Andraos**, P.G. Jessop*, Choosing the Greenest Synthesis: a multivariate metric green chemistry exercise, *J. Chem. Educ.* **2012**, 89, 215-220. doi:10.1021/ed200249v

44. L. Werner; A. Machara; B. Sullivan; I. Carrera; M. Moser; T. Hudlicky*, **J. Andraos***, Several Generations of Chemoenzymatic Synthesis of Oseltamivir (Tamiflu): Evolution of Strategy, Quest for a Process-Quality Synthesis, and Evaluation of Efficiency, *J. Org. Chem.*, **2011**, 76, 10050-10067. doi:10.1021/jo2018872

43. J. Andraos*, A Database Tool for Process Chemists and Chemical Engineers to Gauge the Material and Synthetic Efficiencies of Synthesis Plans to Industrially Important Targets, *Pure Applied Chem.* **2011**, 83, 1361-1378. doi:10.1351/PAC-CON-10-10-07 (invited paper)

42. J. Andraos*, Global Green Chemistry Metrics Analysis Algorithm and Spreadsheets: Evaluation of the Material Efficiency Performances of Synthesis Plans for Oseltamivir Phosphate (Tamiflu) as a Test Case, *Org. Process Res. Develop.* **2009**, 13, 161 – 185. doi:10.1021/op800157z

41. J. Andraos*, Kinetic Plasticity and the Determination of Product Ratios for Kinetic Schemes Leading to Multiple Products Without Rate Laws: new methods based on directed graphs, *Can. J. Chem.*, **2008**, 86, 342-357. doi:10.1139/V08-020

40. J. Andraos*, The Contributions of Solomon F. Acree (1875 - 1957) and the Centennial Anniversary of the Discovery of the Acree-Curtin-Hammett Principle", *The Chemical Educator* **2008**, 13, 170-178. doi:10.1333/s00897082118a

39. J. Andraos*, Gauging Material Efficiency, *Canadian Chemical News* **2007**, 59(4), 14 - 17.

38. J. Andraos* and M. Sayed, On the Use of Green Metrics in the Undergraduate Organic Chemistry Lecture and Practicum to Assess the Material Efficiencies of Organic Reactions, *J. Chem. Educ.* **2007**, 84, 1004 – 1011. doi:10.1021/ed084p1004

37. J. Andraos* and J. Izhakova, Perspectives on the Application of Green Chemistry Principles to Total Synthesis Design, *Chimica Oggi/The International Journal of Industrial Chemistry and Biotechnology*, November/December **2006**, 24(6, Supp.), 31 - 36 (invited article).

36. J. Andraos*, On Using Tree Analysis to Quantify the Material, Input Energy, and Cost Efficiencies of Simple and Complex Synthesis Plans and Networks: toward a blueprint for quantitative total synthesis and green chemistry, *Org. Process Research & Development* **2006**, 10, 212 – 240. doi:10.1021/op0501904

35. J. Andraos*, Reaction Intermediates in Organic Chemistry: The "Big Picture", *Can. J. Chem.* **2005**, 83, 1415 – 1431. doi:10.1139/v05-175

34. J. Andraos*, Scientific Genealogies of Physical Organic and Mechanistic Chemists, *Can. J. Chem.* **2005**, 83, 1400 – 1414. doi:10.1139/v05-158

- 33. J. Andraos***, Unification of Reaction Metrics for Green Chemistry II: Evaluation of Named Organic Reactions and Application to Reaction Discovery, *Org. Process Research & Development*. **2005**, 9, 404 – 431. doi:10.1021/op050014v
- 32. J. Andraos***, Unification of Reaction Metrics for Green Chemistry: Applications to Reaction Analysis, *Org. Process Research & Development* **2005**, 9, 149 – 163. doi:10.1021/op049803n
- 31. S. Ebner, B. Wallfisch, J. Andraos**; I. Aitbaev, M. Kiselewsky, P.V. Bernhardt, G. Kollenz, C. Wentrup, N-aminopyrroledione-hydrazoketene-pyrazolium oxide-pyrazolone rearrangements and pyrazolone tautomerism, *Org. Biomol. Chem.* **2003**, 1, 2550 – 2555. doi:10.1039/B304070D
- 30. J. Andraos***, The Quantification and Optimization of Dynamic Kinetic Resolution, *J. Phys. Chem. A* **2003**, 107, 2374 – 2387. doi:10.1021/jp0272365
- 29. N. Bhardwaj, J. Andraos, C.C. Leznoff**, The Syntheses and NMR Studies of Hexadeca- and Octaneopentoxypthalocyanines, *Can. J. Chem.* **2002**, 80, 141 – 147. doi:10.1139/v02-002
- 28. N.C. deLucas, J.C. Netto-Ferreira, J. Andraos, J.C. Scaiano**, Nucleophilicity toward Ketenes: Rate Constants for Addition of Amines to Aryl Ketenes in Acetonitrile Solution, *J. Org. Chem.* **2001**, 66, 5016 – 5021. doi:10.1021/jo005752q
- 27. J. Andraos** and A.J. Kresge, Correlation of Rates of Uncatalyzed and Hydroxide-Ion Catalyzed Ketene Hydration. A Mechanistic Application and Solvent Isotope Effects on the Uncatalyzed Reaction, *Can. J. Chem.* **2000**, 78, 508 – 515. doi:10.1139/v00-032
- 26. J. Andraos***, Bimolecular Kinetics at Low Temperatures Using FT-IR Matrix Isolation Spectroscopy: Some Caveats. Thermokinetic Parameters for the Reaction of Fulvenones with Pyridine in Pyridine Matrices, *J. Phys. Chem. A*. **2000**, 104, 1532 – 1543. doi:10.1021/jp993648a
- 25. X. Ye, J. Andraos, H. Bibas, M.W. Wong, and C. Wentrup**, Mesoions and ketene valence isomers. Pyrrolo [1,2-*a*]pyridiniumolates and (2-pyridyl)carbonylketenes, *J. Chem. Soc. Perkin I* **2000**, 401 – 406. doi:10.1039/A906831G
- 24. J. Andraos***, E. Lathioor, and W. Leigh, Simultaneous pH-Rate Profiles Applied to the Two Step Consecutive Sequence $A \Rightarrow B \Rightarrow C$: A Theoretical Analysis and Experimental Investigation, *J. Chem. Soc. Perkin 2 Trans.*, **2000**, 365 – 374. doi:10.1039/A905324G
- 23. J. Andraos***, A Streamlined Approach to Solving Simple and Complex Kinetic Systems Analytically, *J. Chem. Educ.* **1999**, 76, 1578 – 1583. doi:10.1021/ed076p1578
- 22. J. Andraos***, The Problem of Distinguishability of Rate Constants in the Two Step Consecutive Sequence $A \Rightarrow B \Rightarrow C$, *Can. J. Chem.* **1999**, 77, 565 – 576. doi:10.1139/v98-227
- 21. J. Andraos, Y. Chiang, S.J. Eustace, A.J. Kresge, S.W. Paine, V.V. Popik, and K. Sung**, Solvent Isotope Effect on the Hydroxide-Ion Catalyzed Hydration of Ketenes in Aqueous Solution, *Can. J. Chem.* **1999**, 77, 459 – 462. doi:10.1139/v99-058
- 20. J. Andraos***, How Mathematics Figures in Chemistry: Some Examples, *J. Chem. Educ.* **1999**, 76, 258 – 267. doi:10.1021/ed076p258
- 19. J. Andraos, G.G. Barclay, D.R. Medeiros, M.V. Baldovi, J.C. Scaiano, and R. Sinta**, Model Studies on the Photochemistry of Phenolic Sulfonate Photoacid Generators, *Chem. Mater.* **1998**, 10, 1694 – 1699. doi:10.1021/cm980052b
- 18. J. Finnerty, J. Andraos, Y. Yamamoto, M.W. Wong, and C. Wentrup**, A Facile 1,3-Shift of Chlorine in a Chlorocarbonylketene, *J. Am. Chem. Soc.* **1998**, 120, 1701 – 1704. doi:10.1021/ja973242g

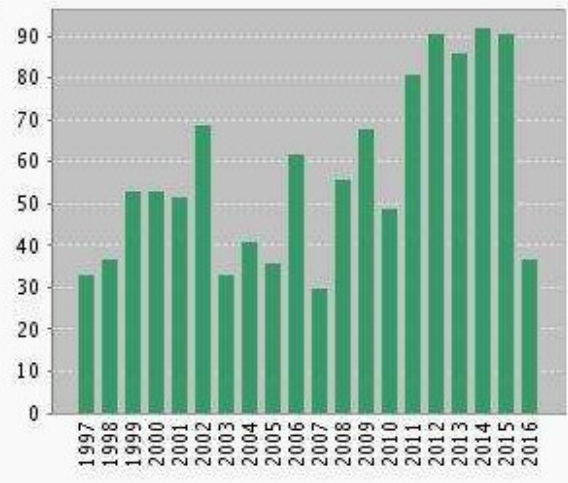
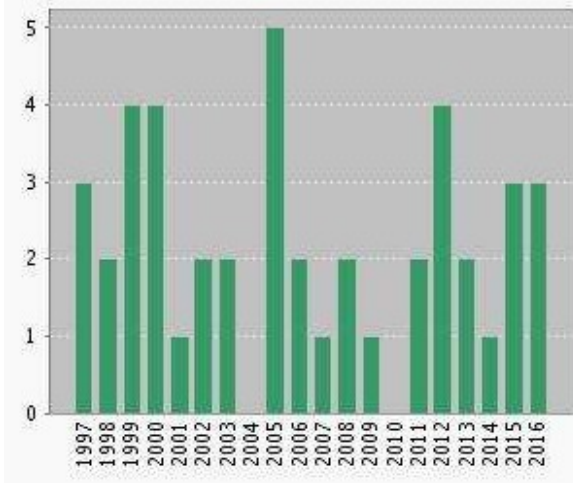
17. **J. Andraos**, Y. Chiang, A.J. Kresge, and V.V. Popik, Flash Photolysis of 10-Diazo-9(10*H*)-phenanthrenone in Aqueous Solution. Hydration of Fluorenylidene ketene and the Fluorene-9-carboxylic Acid Keto-Enol System, *J. Am. Chem. Soc.* **1997**, 119, 8417 – 8424. doi:10.1021/ja971381s
16. N.C. deLucas, J.C. Netto-Ferreira, **J. Andraos**, J. Luszyk, B.D. Wagner, and J.C. Scaiano, Reactivity of Fluorenylidene ketene Towards Amines: A Laser Photolysis Study with Ultraviolet and Infrared Detection, *Tetrahedron Lett.* **1997**, 38, 5147 – 5150. doi:10.1016/S0040-4039(97)01115-5
15. G.G.H. Qiao, **J. Andraos**, and C. Wentrup, Reactivity of Ketenes in Matrices: Direct Observation of Ketene-Pyridine Ylides, *J. Am. Chem. Soc.* **1996**, 118, 5634 – 5638. doi:10.1021/ja9607190
14. **J. Andraos***, On the Propagation of Statistical Errors for a Function of Several Variables, *J. Chem. Educ.* **1996**, 73, 150 – 154. doi:10.1021/ed073p150
13. **J. Andraos**, A.J. Kresge, and N.P. Schepp, The Hydration of Mesitylketene in Aqueous Solution: Detection of Acid Catalysis for an Aromatic Ketene, *Can. J. Chem.* **1995**, 73, 539 – 543. doi:10.1139/v95-069
12. J.C. Scaiano, N.C. deLucas, **J. Andraos**, and H. Garcia, Determination of the Distance for Triplet Energy Transfer in the Faujasite NaY, *Chem. Phys. Lett.* **1995**, 233, 5 – 8. doi:10.1016/0009-2614(94)01448-5
11. N.C. deLucas, **J. Andraos**, J.C. Netto-Ferreira, and J.C. Scaiano, Laser Flash Photolysis Study of the Reactivity of alpha-Ketenylbenzocyclobutenone with Water and Alcohols, *Tetrahedron Lett.* **1995**, 36, 677 – 680. doi:10.1016/0040-4039(94)02350
10. **J. Andraos**, Y. Chiang, A.S. Grant, H.X. Guo, and A.J. Kresge, The pK_a of an Acetylenic Amine, N-(pentafluorophenyl)-2-phenylethynamine, Ionizing as an Acid in Aqueous Solution, *J. Am. Chem. Soc.* **1994**, 116, 7411 – 7412. doi:10.1021/ja00095a056
9. **J. Andraos**, A.J. Kresge, and V.V. Popik, Kinetics and Mechanism of the Isomerization of 1*H*-Indene-1-carboxylic Acid to 1*H*-Indene-3-carboxylic Acid in Aqueous Solution and Determination of their Keto-Enol Equilibrium Constants for the Keto and Enol Forms. Implication on the Photolysis of Diazonaphthoquinones, *J. Am. Chem. Soc.* **1994**, 116, 961 – 967. doi:10.1021/ja00082a017
8. **J. Andraos**, Y. Chiang, A.J. Kresge, I.G. Pojarlieff, N.P. Schepp, and J. Wirz, The alpha-Cyano-alpha-phenylacetic Acid Keto-Enol System. Flash Photolytic Generation of the Enol in Aqueous Solution and Determination of the Keto-Enol Equilibrium Constants and Acid Dissociation Constants Interrelating all Keto and Enol Forms in that Medium, *J. Am. Chem. Soc.* **1994**, 116, 73 – 81. doi:10.1021/ja00080a009
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