

Curriculum Vitae

BRADLEY RAY ARNOLD

Education:

- 1995 Ph.D. Chemistry University of Utah, Salt Lake City, Utah. Chemistry
- 1983 B. Sc. H. Chem. Dalhousie University, Halifax, Nova Scotia, Canada. Chemistry

Experience in Higher Education:

- 2001-present University of Maryland, Baltimore County, Baltimore, Maryland. Associate Professor, Physical Chemistry.
- 1998-present University of Maryland Baltimore County
Regular Member of the Graduate Faculty
- 2006 - 2010 University of Maryland Baltimore County
Graduate Program Director, Department of Chemistry & Biochemistry
- 1995 - 2001 University of Maryland, Baltimore County, Baltimore, Maryland. Assistant Professor, Physical Chemistry.
- 1995 -1998 University of Maryland Baltimore County
Associate Member of the Graduate Faculty

Experience in Other than Higher Education:

- 2018 - present NuMoon Spectroscopy, LLC. Columbia, Maryland.
Founder and Chief Science Officer
- 2010 - 2011 U.S. Army Research Laboratory (Adelphi Research Center)
Visiting Scientist, Sensors and Electron Devices Directorate
- 1993-1995 Center for Photoinduced Charge-Transfer, Rochester, New York, Research Associate.
- 1990-1993 National Research Council of Canada, Ottawa, Canada.
Research Associate.

Honors Received:

- 2024 Elected Senior Member of SPIE
- 2022 Associate Editor of Optical Engineering
- 2022 Carl Weber Excellence in Science and Mathematics Teaching Award
- 2019 Elected Fellow of the Royal Society of Chemistry
- 2019 ACS Mid-Atlantic Regional Meeting, Program Co-Chair
- 2016 Member, Research and Creative Achievement Council
- 2016 Research and Creativity Council Member, UMBC
- 2012 ACS Mid-Atlantic Regional Meeting, Program Co-Chair
- 2008 Member, UMBC Senate, Grievance Committee
- 2006 Member, UMBC/UMB Graduate Council
- 2006 Graduate Council, UMBC/UMB
- 2005 Chair, Chemistry/Biology Machinist Search Committee
- 2004 Chair, Chemistry/Biology Technician Search Committee
- 2002 Inter-American Photochemistry Society Advisory Council
- 1996 Editorial Board Member of Spectroscopy Letters

Research Support and Fellowships

“Sample preparation for Raman Spectrograph Calibration and assessment of limits of detection.” NuMoon Technologies, 06/01/2021 – 08/31/2024

\$10 000

Technical support for NuMoon Technologies.

“Hand-Held Proximal Optical Surface Contaminant Detection Project” subcontract from Scitech Services under DoD contract: W911SR-20-F-0048 05/01/2021 – 09/30/2022

\$99 989.28

Project to build prototype of a proximal Raman Spectrograph.

“Advancement of Non-Linear Raman Spectroscopy for Dual-Use Applications”

ARL ECBC JSW 1410C. Dates: 07/1/14 – 6/30/22

\$750 000

This project examines novel analytical techniques applicable to proximal detection.

“Multi-wavelength Raman Spectroscopy Technology Prototype for Test and Evaluation”

Army Contracting Command W911SR-18-R-RSSP. Dates 10/1/2019 – 9/30/2021

\$480 000

This project examines multi-wavelength visible to deep-UV Raman spectroscopy as a potential technique applicable to rapid proximal detection of hazardous materials.

“Apogee Scanner”

MII TEDCO Phase III. Dates 06/1/2019 – 2/28/2021

\$150 000

To develop a package scanning system for DHS applications based on UV-Raman technology. Funding to NuMoon Technologies.

“Apogee Scanner”

MII TEDCO Phases I and II Dates 03/1/2018 – 02/28/2019

\$115 000

Development of NuMoon Technologies based on Raman techniques licensed from UMBC.

Thesis and Postgraduate Scholars

Leslie Schuerer	UMBC	Ph.D. expected 2025
Eric Bowman	UMBC	Ph.D. expected 2025
Christopher Cooper	UMBC	Ph.D. 2023
Justin Curtus	Edgewood Chemical Biological Center	Masters 2018
Jeffery Oleske	Specim Technology	Ph.D. 2015
Suz Daphnes	Baltimore School District	Masters 2010
Mark N'Dumae	unknown	Masters 2008
Bae, S.Y.	Aberdeen Proving Grounds	Ph.D. 2006
Levy, D.	Gentex Corp. Simpson PA.	Ph.D. 2005
Lu, X.F.	U. of Maryland, Baltimore County	Masters 2004
McKim, W.D.	Battelle Institute	Masters 2004
Poliakov, P.V.	Brookhaven National Lab	Ph.D. 2001

Publications:

Articles in Refereed Journals

1. Singh, N.B.; Su, C.H.; Choa, F.S.; Arnold, B.R.; Cullum, B.; Mandal K.D. Morphological evolution and transition at nanoscale in BSTO ceramic materials” *Ferroelectrics*, **2023**, 611, 268-278.
2. Arnold, B.R.; Tahir, S.; Lecha, S. “Laser-based optical technique for proximal collection of chemical signatures” SPIE Proceedings 12541, CBRNE Sensing XXIV, **2023**, 1254105.

3. Setera, B.; Su, C.H.; Arnold, B.R.; Choa, F.-S.; Kelly, L.; Sood, R.; Singh, N.B. "Performance of Bulk and Nanoengineered Doped ZnSe" *Crystals*, **2022**, *12*, 71.
4. Singh, N.B.; Su, C.H.; Choa, F.S.; Arnold, B.R.; Gill, P.; Charmain, S.; Emge, I.; Sood, R. *Crystals* **2020**, *10*, 551. doi:10.3390/cryst10070551
5. Singh, N.B.; Choa, F.S.; Su, C.H.; Cullum, B.; Arnold, B.R.; Kelly, L. "Morphology and performance of organic nanocomposites for γ -ray sensing" *J. Emerging Materials Research* **2020**, *1*(4), 212.
6. Arnold, B.R.; Bowman, E.; Schuerer, L. "Deep-UV standoff Raman spectroscopy", *Proceedings of SPIE* **2019**, 10983, 109830H.
7. Singh, N.B.; Choa, F.S.; Arnold, B.R.; Su, C.H.; Kelly, L.; Mandal, K.D.; Singh, N. "Morphological transition and evolution of shapes in glassy state" *Advances in Ceramics for Environmental, Functional, Structural and Energy Applications II*, **2019**, 68.
8. Singh, N.B.; Su, C.H.; Arnold, B.R.; Choa, F.S.; Kelly, L.; Agarwal, N.; Sova, Cooper, C. "Effect of pH and sugar on the crystallization of multinary oxides; Morphology, bulk transparency and thermal characteristics of kidney stones" *J. Science and Technology* **2019**, *9*(1), 11.
9. Singh, N., Su, C.-H., Arnold, B., Choa, F.-S., Cullum, B. M., Sova, S., Cooper, C. "Morphological and Optical Characteristics of Transition Metal Doped PVT Grown Zinc Selenide Single Crystal", *Crystal Research and Technology*, **2019**, *54*(4), 1800231
10. Singh, N.; Choa, F.-S.; Su, C.-H.; Cullum, B. M.; Arnold, B.; Kelly, L. A. "Morphology and performance of organic nanocomposites for gamma-ray sensing" *J. Emerging Materials Research*. **2019**,
11. Arnold, B.R.; Cooper, C.E., Matrona, M.R.; Emge, D.K.; Oleske, J.B. "Stand-off Deep-UV Raman Spectroscopy" *Can. J. Chem.* **2018**, *96*, 614-620.
12. Arnold, B.R.; Couturier, N.; Gushen, C.; Wheatley, C. "Independent Evaluation of the GAM EX5ALN Miniature Line-Narrowed KrF Excimer Laser" RDECOM Tech. Rep. ECBC-CR-163, **2017**, *163*, 9-25.
13. Singh, N.B., Su, C.-H., Arnold, B.R., Choa, F.-S., Sova, S., Cooper, C. "Multifunctional 2D-Materials: Gallium Selenide", *Materials Today: Proc.* **2017**, *4*, 5471-5477.
14. Singh, N.B., Cooper, C., Strobbia, P., Prasad, N., Su, C.-H., Arnold, B.R., Choa, F.-S., "Nanomorphology and performance of pure and doped lead selenide for infrared detector," *Optical Engineering*, **2017**, *56*, 71106.
15. Singh, N.B., Su, C.-H., Arnold, B.R., Choa, F.-S., "Optical and morphological characterization of zinc-selenide - zinc sulfide solid solution crystals," *Optical Materials*, **2016**, *60*, 474-480.
16. Singh, N. B., Su, C.-H., Arnold, B.R., Choa, F.-S., Nagaradona, T., "Effect of impurities and growth parameters on the quality of Ti_3AsSe_3 optical crystal," *Optical Materials*, **2016**, *60*, 81-85.
17. Singh, N. B., Schreib, B., Devilbiss, M., Loiacono, J., Arnold, B.R., Choa, F.-S., Mandal, K.D. "Low temperature processing of dielectric perovskites for energy storage" *SPIE*, **2016**, 986509.
18. Arnold, B.R., Roberson, S.D., Pellegrino, P.M., "Repopulation of Nitrogen Excited Triplet State Following Laser Induced Filamentation," *J. Phys. Chem*, **2014**, *118*, 10456 - 10463.
19. McKim, W.D., Ray, J., Arnold, B.R., "Analysis of the association constants for charge-transfer complex formation," *J. Mol. Struct.*, **2013**, *1033*, 131-136.

20. Singh, N. B., Gillan, M., House, D., Yanamaddi, R., Razdan, V., Arnold, B.R. "Effect of substitution and impurities on dielectric properties and resistivity of $\text{CaCu}_3\text{Ti}_4\text{O}_{12}$ " *J. Emerging Materials Research* **2013**, 2(6), 344-347.
21. Singh, N. B., Berghmans, A., King, M., Knuteson, D., Talvacchio, J., Kahler, D., House, M., Schreib, B., Wagner, B., McLaughlin, S. "Modification of interface anisotropy and its effect on microstructural evolution during Ostwald ripening" *Crystal Research and Technology* **2013**, 18(11), 983-988.
22. Singh, N.B., House, D., Arnold, B.R. "Novel IR Detector Materials: Hyperstructure and meta morphology formation in heavy metal Chalcogenides" *Journal of Advance Materials Manufacturing and Characterization* **2013**, 3(2), 15-19.
23. Arnold, B.R., Roberson, S.D., Pellegrino, P.M., "Excited state dynamics of nitrogen reactive intermediates at the threshold of laser induced filamentation," *Chem. Phys.*, **2012**, 405, 9-15.
24. Arnold, B.R., Kelly, L.A., Oleski, J., Schill, A.W., "Stand-off detection of Nitrotoluenes using 213-nm amplified spontaneous emission from nitric oxide," *Anal. Bioanal. Chem.*, **2009**, 395, 349-355.
25. Arnold, B.R., Levy, D., Lu, X.; "Rotational Dynamics of Excited Probes: Testing Hydrodynamic Theories Using Time-Resolved Linear Dichroism Data" *Spec. Lett.* **2007**, 40, 149-164.
26. Schill, Alexander W., Arnold, Bradley R., Kelly, Lisa A., Pellegrino, Paul M., "Standoff detection using coherent backscattered spectroscopy," *SPIE Proceedings*, **2007**, 6554, 65540g.
27. Schill, A.W., Heaps, D. A., Stratis-Cullum, D. N., Arnold, B. R., Pellegrino, P. M., "Characterization of near-infrared low energy ultra-short laser pulses for portable applications of laser induced breakdown spectroscopy," *Opt. Express*, **2007**, 14044-14056.
28. Levy, D., Arnold, B.R.; "Influence of Localized Excited States on the Transition Moment Direction of Charge-Transfer Complex Absorptions" *J. Phys. Chem. A* **2005**, 109, 2113-2119.
29. Levy, D., Arnold, B.R.; "Analysis of Charge-Transfer Absorption and Emission Spectra on an Absolute Scale: Evaluation of Free Energies, Matrix Elements, and Reorganization Energies" *J. Phys. Chem. A* **2005**, 109, 8572-8578.
30. Levy, D., Arnold, B.R.; "The Nature of the Rapid Relaxation of Excited Charge-Transfer Complexes" *J. Am. Chem. Soc.* **2004**, 126, 10727-10731.
31. Bae, S.Y., Arnold, B.R.; "Characterization of Solvatochromic Probes: Simulation of Merocyanine 540 Absorption Spectra in Binary Solvent Mixtures and Pure Solvent Systems" *J. Phys. Org. Chem.* **2004**, 17, 187-193.
32. Levy, D., Arnold, B.R.; "Application of Time-Resolved Linear Dichroism Spectroscopy: Intensity Borrowing in Charge Transfer Complex Absorption Spectra" *Can. J. Chem.* **2003**, 81, 567-574.
33. Arnold, B.R., Schill, A.W.; "Rotational Dynamics of Excited Probes: The Analysis of Experimental Data" *Spec. Lett.* **2002**, 35, 229-238.
34. Murray, G.M., Arnold, B.R., Kelly, C.A., Uy, O.M.; "Imprinted Polymer Sensors for Contamination Detection" *Proc. SPIE – Int. Soc. Opt. Eng.*, **2001**, 4206, 131.
35. Arnold, B.R., Schill, A., Poliakov, P.V.; "Application of Time-Resolved Linear Dichroism Spectroscopy: Relaxation of Excited Hexamethylbenzene/1,2,4,5-Tetracyanobenzene Charge-Transfer Complex" *J. Phys. Chem. A*, **2001**, 105, 537-543.

36. Arnold, B.R., Euler, A.C., Schill, A.W., Poliakov, P.V.; "Application of Time-Resolved Linear Dichroism Spectroscopy: Rapid Relaxation of Excited Charge-Transfer Complexes" *J. Phys. Chem. A*, **2001**, 105, 10404-10412.
37. Arnold, B.R., Zaini, R., Euler, A.; "Analysis of Charge-Transfer Complex Absorption Spectra and the Applicability of the Mulliken Two-State Model" *Spec. Lett.* **2000**, 33, 595-614.
38. Arnold, B.R., Euler, A., Fields, K., Zaini, R.; "Association Constants for 1,2,4,5-Tetracyanobenzene and Tetracyanoethylene with Methyl Substituted Benzenes Revisited" *J. Phys. Org. Chem.* **2000**, 13, 729-734.
39. Zaini, R.Y., Orcutt, A.C., Arnold, B.R.; "Determination of Equilibrium Constants for Weakly Bound Charge-Transfer Complexes" *Photochem. Photobiol.* **1999**, 69, 443-447.
40. Arnold, B.R., Euler, A.C., Jenkins, A.L., Uy, O.M., Murray, G.M.; "Progress in the Development of Molecularly Imprinted Polymer Sensors" *Johns Hopkins APL Tech. Digest*, **1999**, 20, 190-198.
41. Poliakov, P.V., Arnold, B.R.; "An Application of Time-Resolved Linear Dichroism Spectroscopy: The Excited Singlet State of 1,2:5,6-Dibenzanthracene" *Spec. Lett.* **1999**, 32, 747-762.
42. Wagner, B.D., Arnold, B.R., Brown, G.S., Luszytk, J.; "Spectroscopy and Absolute Reactivity of Ketenes in Acetonitrile Studied by Laser Flash Photolysis with Time-Resolved Infrared Detection" *J. Am. Chem. Soc.* **1998**, 120, 1827-1834.
43. Arnold, B.R., Atherton S.J., Farid, S., Goodman, J.L., Gould, I.R.; "Combined Application of Picosecond Transient Absorption and Emission Measurements in Studies of Radical-Ion Pair Dynamics" *Photochem. Photobiol.* **1997**, 65, 15.
44. Arnold, B.R., Farid, S., Goodman, J.L., Gould, I.R.; "Absolute Energies of Interconverting Contact and Solvent-Separated Radical-Ion Pairs" *J. Am. Chem. Soc.* **1996**, 118, 5482.
45. Arnold, B.R., Noukakis, D., Farid, S., Goodman, J.L., Gould, I.R.; "Dynamics of Interconversion of Contact and Solvent-Separated Radical-Ion Pairs" *J. Am. Chem. Soc.* **1995**, 117, 4399.
46. Scaiano, J.C., Arnold, B.R., McGimpsey, W.G.; "Two-Laser, Two-Color Photochemistry from Upper Triplet States of 2-Bromonaphthalene and 9-Bromophenanthrene in Benzene" *J. Phys. Chem.* **1994**, 98, 5431.
47. Arnold, B.R., Brown, C. E., Luszytk, J.; "Solution Photochemistry of 2H-Pyran-2-one: Laser Flash Photolysis with Infrared Detection of Transients" *J. Am. Chem. Soc.* **1993**, 115, 1576.
48. Ha, C., Horner, J.H., Newcomb, M., Varick, T.R., Arnold, B.R., Luszytk, J.; "Kinetic Studies of the Cyclization of the 6,6-Diphenyl-5-hexenyl Radical. A Test of the Accuracy of the Rate Constants for Reactions of Hydrogen Atom Transfer" *J. Org. Chem.* **1993**, 58, 1194.
49. Arnold, B.R., Michl, J.; "Ultraviolet and Polarized Infrared Spectroscopy of Matrix-Isolated Cyclobutadiene and Its Isotopomers" *J. Phys. Chem.* **1993**, 97, 13348.
50. Arnold, B.R., Scaiano, J.C.; "Laser ablation of Doped Polymers: Transient Phenomena as the Ablation Threshold is Approached" *Macromolecules* **1992**, 25, 1582.
51. Arnold, B.R., Scaiano, J.C., McGimpsey, W.G.; "Electron Transfer Quenching of Excited Diphenylmethyl Radical" *J. Am. Chem. Soc.* **1992**, 114, 9978.
52. Arnold, B.R., Scaiano, J.C., Bucher, G.F., Sander, W.W.; "Laser Flash Photolysis Studies on 4-Oxo-cyclohexa-2,5-dienylidenes" *J. Org. Chem.* **1992**, 57, 6469.

53. Arnold, B.R., Radziszewski, J.G., Campion, A., Perry, S.S., Michl, J.; "Raman Spectrum of Matrix-Isolated Cyclobutadiene. Evidence for Environmental Hinderance to Heavy-Atom Tunneling?" *J. Am. Chem. Soc.* **1991**, *113*, 692.
54. Arnold, B.R., Balaji, V., Downing, J.W., Radziszewski, J.G., Fisher, J.J., Michl, J.; "IR Polarization Directions in *s-trans*-1,3-Butadiene and the Average Topochemistry of the *s-Cis* to *s-Trans* Photoisomerization in Matrix Isolation" *J. Am. Chem. Soc.* **1991**, *113*, 2910.
55. Arnold, B.R., Balaji, V., Michl, J.; "Structure of Matrix-Isolated *s-cis*-1,3-Butadiene from Polarized IR Spectra: A Closer Look" *J. Am. Chem. Soc.* **1990**, *112*, 1808.
56. Orendt, A.M., Arnold, B.R., Radziszewski, J.G., Facelli, J.C., Malsch, K.D., Stub, H., Grant, D.M., Michl, J.; "¹³C NMR and Polarized IR Spectra of Vicinally Labeled [¹³C₂] Cyclobutadiene in Ar Matrix: Interconversion of Valence Tautomers" *J. Am. Chem. Soc.* **1988**, *110*, 2648.
57. Arnold, B.R., Donald, L., Jurgens, A., Pincock, J.A.; "Homolytic Versus Heterolytic Cleavage for the Photochemistry of 1-Naphthylmethyl Derivatives" *Can. J. Chem.* **1985**, *63*, 3140.
58. Loutfy, R.O., Arnold, B.R.; "Effect of Viscosity and Temperature on Torsional Relaxation of Molecular Rotors" *J. Phys. Chem.* **1982**, *86*, 4205.

Book Chapters and Review Articles.

1. Arnold, B.R., Levy, D., McKim, W.D.; "Association Constants of Weakly Bound Charge Transfer Complexes" *The Spectrum* **2003**, *16*, 8-11.
2. Arnold, B.R.; review of Advances in Photochemistry, vol. 23., *Photochem. Photobiol.* **1998**, *68*, 133.
3. Arnold, B.R., Scaiano, J.C.; "Reactions of Excited Free Radicals in Solution" in Landolt-Bernstein Numerical Data and Functional Relationships in Science and Technology, H. Fiesher, Ed., Springer-Verlag: New York, N. Y., 1998.
4. Arnold, B.R., Zaini, R., Orcutt, A.C., "Determination of Equilibrium Constants for Weakly Bound Charge Transfer Complexes", *IAPS Newsletter*, **1998**, *21(2)*, 18-24.
5. Arnold, B.R., Michl, J.; "Spectroscopy of Cyclobutadiene", in Kinetics and Spectroscopy of Carbenes and Biradicals, M. Platz, Ed., Plenum: New York, N. Y., 1990.

Patents

1. U.S. Patent 10078013, **2018**, Arnold, B.R., et al., Systems and Methods Using Multi-wavelength Single-Pulse Raman Spectroscopy.
2. -insert IR emission discl
3. -insert ALSiC heat spreader discl.
4. -insert BASE app.
5. -insert Templated Resins patent .

Presentations: (IS ≡ Invited Seminar, P ≡ Poster Presentation)
 CBRN Defense, Test and Evaluation Standards Development, March 2021 (IS virtual)
 IAPS Winter Conference, Sarasota, Florida, January 2018 (P)
 BHU Varanasi, India, October 2017 (Keynote)
 Department of Chemistry, Millersville University, Millersville, PA. Nov 2016 (IS)

3rd Sustainable Science, Technology, Human Health and Environment for a Global Society, Baltimore, MD. March 2015 (IS)

2nd Sustainable Science, Technology, Human Health and Environment for a Global Society, Baltimore, MD. March 2014 (IS)

Department of Chemistry, Johns Hopkins University, Baltimore, MD. Nov 2012 (IS)

Department of Chemistry, Gettysburg College, Gettysburg, PA. March 2011 (IS)

Department of Chemistry, Coppin State, Baltimore, MD. March 2008 (IS)

Gordon Conference Radicals and Radical Ions, July 2007 (IS)

Department of Chemistry, University of Puerto Rico, San Pdras, April 2006. (IS)

Reactive Intermediates Symposium, University of Ottawa, Ottawa, Ontario, 2005 (IS)

Gordon Conference on Organic Photochemistry, Bryant University, Rhode Island,
July 2005 (P)

Department of Chemistry, Dalhousie University, Halifax, Nova Scotia, August 2002 (IS)

Department of Chemistry, Lincoln University, Pennsylvania, March 2002 (IS)

Thirteenth IAPS Winter Conference, Tempe, Arizona, January 2002 (P)

Department of Chemistry, Florida State University, Tallahassee, Florida,
September 2001 (IS)

Eleventh IAPS Winter Conference, Clearwater, Florida, January 2000 (P)

Gordon Conference on Organic Photochemistry, Newport, Rhode Island, July 1999 (P)

27TH American Society for Photobiology Meeting, Washington, D.C., July 1999 (IS)

Ninth IAPS Winter Conference, Clearwater, Florida, January 1998 (IS)

Physics Department, University of Maryland, Baltimore County, September 1997 (IS)

Gordon Conference on Organic Photochemistry, Newport, Rhode Island, July 1997 (P)

Department of Chemistry, Georgetown University, Washington D.C.,
November 1996 (IS)

United States-Latin American Workshop on Time-Resolved Techniques in Photochemistry, Photophysics
and Photobiology, Foz do Iguacu, Brazil, May 1996 (IS)

Eighth IAPS Conference, Foz do Iguacu, Brazil, May 1996 (P)

Department of Chemistry, University of Maryland, College Park, March 1996 (IS)

Gordon Conference on Organic Photochemistry, Newport, Rhode Island, July 1995 (P)

International Conference on Radical Ions, Dalhousie University, Halifax, Nova Scotia,
August 1994 (P)

Gordon Conference on Organic Photochemistry, Newport, Rhode Island, July 1993 (P)

Department of Chemistry, Boston University, Boston, Massachusetts February 1993 (IS)

Fifth IAPS Winter Conference, Clearwater, Florida, January 1993 (P)

Department of Chemistry, Dalhousie University, Halifax, Nova Scotia,
December 1992 (IS)

Twentieth Ontario-Quebec Physical-Organic Mini-Symposium, McGill University, Montreal, Quebec,
October 1992 (IS)

Gordon Conference on Free Radical Chemistry, New London, New Hampshire,
July 1991 (P)

Department of Chemistry, Worcester Polytechnic Institute, Worcester, MA,
April 1991 (IS)

Structure and Reactivity Symposium, The University of Texas at Austin, Austin, Texas,
March 1989 (P)

Second IAPS Winter Conference, Clearwater, Florida, January 1989 (P)

The contents of this CV are accurate and true.



Bradley Arnold