CURRICULUM VITÆ — Mark Keil

professional address	*personal address*	*biographical*	
Mark Keil, Dept. of Physics	Mark and Heddi Keil	Birth Date:	February 3, 1953
Ben-Gurion University of the Negev	Ha'Hashmona'im 39/15	Birth Place:	Montreal, Canada
Be'er Sheva, Israel 84105	Ra'anana, Israel 43256	Citizenship:	Israel, Canada, U.S.A.
tel: (08)647-7669; (08)646-1902	(09)743-8156, **(054)740-7621**	Personal:	Married, 5 children
fax: (08)647-9264		Aliyah:	December 25, 2001
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EDUCATION:

Post-Doctoral	with Prof. John C. Polanyi in Chemistry
1978–1980	University of Toronto, Toronto, Ontario M5S 1A1, Canada
research:	Laser-selected state-to-state energy transfer processes in molecular beams.
Ph.D.	with Prof. Aron Kuppermann in Chemistry, emphasis in Chemical Physics
1973–1978	California Institute of Technology, Pasadena, California 91125, USA
thesis title:	"Interaction Potentials of He with Atoms and Molecules from Crossed Beam Experiments."
A.B.	cum laude, with High Honours in Chemistry
1969–1973	Colgate University, Hamilton, New York 13346, USA

EMPLOYMENT HISTORY:

2005–present:	Physicist, Ben-Gurion University of the Negev, Department of Physics
2003–05:	*Amit Haver* (Staff Scientist), Weizmann Institute of Science, Department of Chemical Physics
2000–03:	Visiting Scientist, Weizmann Institute of Science, Department of Chemical Physics
1999–00 & '03:	Belkin Visiting Professor, Weizmann Institute of Science, Department of Chemical Physics
2000:	Lady Davis Visiting Professor, Technion, Department of Chemistry
2003–present:	Scientific Consultant, University of British Columbia, Department of Chemistry
2000–present:	Adjunct Professor, University of Oklahoma, Department of Physics & Astronomy
1995–00:	Professor, University of Oklahoma, Department of Physics & Astronomy **(tenured, 1995)**
1992–95:	Associate Professor, University of Oklahoma, Department of Physics & Astronomy
1992–93:	Adjunct Professor, University of Alberta, Department of Chemistry
1989–92:	Associate Professor, University of Alberta, Department of Chemistry **(tenured)**
1982–89:	Assistant Professor, University of Alberta, Department of Chemistry **(tenured, 1988)**
1980–82:	Killam Research Associate (Canada Council), University of Toronto, Department of Chemistry
1978–80:	Post-Doctoral Fellow, University of Toronto, Department of Chemistry

RESEARCH AREAS and QUALIFICATIONS:

Quantum, Optical, Surface, and Chemical Physics:

- Ultracold atomic physics; Bose-Einstein condensation
- Coherent control of chemical reactivity; phase-locked nsec lasers
- Semiconductor surface etching
- State-to-state chemical reactions and collision dynamics
- Intermolecular energy transfer and potential energy surfaces
- Van der Waals molecules
- Computational chemical dynamics

Experimental techniques:

- High-resolution lasers for atomic and molecular spectroscopy
- Advanced design of magnetic, electrostatic, and optical fields
- High-power lasers for non-linear spectroscopy and interferometry
- High- and ultra-high vacuum, design and construction
- Mass spectroscopy, liquid He cryogenics, and low-temperature bolometry
- Molecular beams, including high-temperature and corrosive gases, and cold atomic and molecular beams
- Silicon nanostructures using atomic beams
- Computer interfacing, design, graphics, and data reduction

RESEARCH FUNDING (PI or co-PI):

1999–present:	Weizmann Institute (Belkin Fellowship), ~\$54,000/2 years; Technion (Lady Davis Fellowship), ~\$7,500/1 year; Ministry of Immigrant Absorption of Scientists, ~\$18,000/2 years; Fritz-Haber Centre, ~\$32,000/5 years;
1997–00:	National Science Foundation, \$393,115/4 years; American Chemical Society (Petroleum Research Fund), \$50,000/2 years; University of Oklahoma (Research Council), \$24,815/1 year; Oklahoma State Regents, \$440,000/3 years (with 7 other co-PI's).

PATENT: "Method and Apparatus for Etching Surfaces with Atomic Fluorine", U.S. Patent #5,597,495.

PROFESSIONAL REFERENCES: available on request

Oct. 19, 2006

INVITED TALKS at INTERNATIONAL MEETINGS:

Q. Zhang, M. Keil, and M. Shapiro,
"Coherent Control and the Phase Locking of Two-Photon Processes in the Nanosecond Domain",
Frontiers in Optics/Laser Science XX (Optical Society of America),
Rochester, New York, U.S.A., October 10–14, 2004.

Q. Zhang, M. Keil, and M. Shapiro,
"Coherent Control and the Phase Locking of Two-Photon Processes",
German-Israeli Cooperation in Ultrafast Technologies,
Rehovot, Israel, February 16–17, 2004.

Q. Zhang, M. Keil, and M. Shapiro,
"Coherent Control of Na_2 Photodissociation",
XIVth *European Conference on Dynamics of Molecular Collisions–MOLEC2002,*
Istanbul, Turkey, September 1–6, 2002.

Q. Zhang, M. Keil, and M. Shapiro,
"Coherent Control of Na_2 Photodissociation",
Conference on Coherent Control of Molecular Processes,
London, U.K., April 23–24, 2001.

M. Keil,
"Atomic Fluorine Beam Etching of Nano-Scale Features in Silicon",
Israel Vacuum Society,
Holon, Israel, June 12, 2000.

M. Keil, G. Dharmasena, T. R. Phillips, S. Crocchianti, and G. A. Parker,
"Chemical Dynamics for the $F + H_2 \rightarrow HF + H$ Reaction",
Symposium on Molecular Structure and Dynamics, Southwest Regional ACS Meeting,
Baton Rouge, Louisiana, U.S.A., November 1–3, 1998.

M. Keil, G. Dharmasena, T. R. Phillips, S. Crocchianti, and G. A. Parker,
"Initial and Final State Dependence of Angular Distributions for the $F + H_2$ Reaction",
Gordon Research Conference on Atomic and Molecular Interactions,
New London, New Hampshire, U.S.A., June 28–July 3, 1998.

Other Selected Talks

Q. Zhang, M. Keil, and M. Shapiro,
"Conferring Coherence on Incoherent Laser Beams",
University of Kaiserslautern, Department of Physics,
Kaiserslautern, Germany, February 14, 2002.

M. Keil, P. R. Larson, A. M. Elliott, and M. B. Johnson,
"New Tools for Nano-Scale Etching",
Ben-Gurion University,
Be'er Sheva, Israel, March 20, 2001.

M. Keil,
"Atomic Fluorine Beam Etching of Nano-Scale Features in Silicon",
Technion–Israel Institute of Technology, Department of Materials Engineering,
Haifa, Israel, June 15, 2000.

M. Keil,
"Energy Transfer, Chemical Reactions, and Surface Etching using Atomic, Molecular, and Laser Beams",
Technion–Israel Institute of Technology, Department of Chemistry,
Haifa, Israel, April 18, 2000;
Ben-Gurion University,
Be'er Sheva, Israel, November 9, 1999.

M. Keil,
"Chemical Reaction Dynamics for the $F+H_2$ Reaction: Initial and Final State Dependence of Angular Distributions",
Bar-Ilan University, Department of Chemistry,
Ramat Gan, Israel, April 28, 1999;
Hebrew University, Department of Chemistry,
Jerusalem, Israel, April 26, 1999;
Ben-Gurion University, Department of Chemistry,
Be'er Sheva, Israel, April 25, 1999.

Poster Session Presentations in Ultracold Atomic Physics, Coherent Control of Chemical Reactions, and Chemical Reaction Dynamics: titles, conferences, co-authors available upon request.

Oct. 19, 2006

Refereed Articles
(papers on which Mark Keil is PI or co-PI)*
(† ten most important contributions)
(citations last updated in July, 2005)

*†40. Q. Zhang, M. Keil, and M. Shapiro,
"Coherent Control and Phase Locking of Two-Photon Processes in the Nanosecond Domain",
J. Opt. Soc. Am. B **20**, 2255–2261 (2003). *1 citation, latest citation in 2004.*

39. E. Nikitin, E. Dashevskaya, J. Alnis, M. Auzinsh, E. R. I. Abraham, B. R. Furneaux, M. Keil, C. McRaven, N. E. Shafer-Ray, and R. Waskowsky,
"Measurement and Prediction of the Speed-Dependent Throughput of a Magnetic Octupole Velocity Filter Including Nonadiabatic Effects",
Phys. Rev. A **68**, 023403-1–8 (2003). *1 citation, latest citation in 2004.*

37. G. A. Parker, M. Keil, M. A. Morrison, and S. Crocchianti,
"Quantum Reactive Scattering in Three Dimensions: Using Tangent-Sphere Coordinates to Smoothly Transform from Hyperspherical to Jacobi Regions",
J. Chem. Phys. **113**, 957–970 (2000). *3 citations, latest citation in 2004.*

*†36. P. R. Larson, K. A. Copeland, G. Dharmasena, R. A. Lasell, M. Keil, and M. B. Johnson,
"Atomic Fluorine Beam Etching of Silicon and Related Materials",
J. Vac. Sci. Technol. B **18**, 307–312 (2000). *3 citations, latest citation in 2004.*

*†35. G. Dharmasena, K. Copeland, J. H. Young, R. A. Lasell, T. R. Phillips, G. A. Parker, and M. Keil,
"Angular Dependence for $\nu' j' -$ Resolved States in $F + H_2 \rightarrow HF + H$ Reactive Scattering Using a New Atomic Fluorine Beam Source",
J. Phys. Chem. A **101**, 6429–6440 (1997). *30 citations, latest citation in 2005.*

*†34. G. Dharmasena, T. R. Phillips, K. N. Shokhirev, G. A. Parker, and M. Keil,
"Vibrationally and Rotationally Resolved Angular Distributions for $F + H_2 \rightarrow HF(\nu', j') + H$ Reactive Scattering",
J. Chem. Phys. **106**, 9950–9953 (1997). *29 citations, latest citation in 2005.*

*32. T. Ericson, K. Copeland, M. Keil, Y. Apelblat, and Y. B. Fan,
"Fluoride Salts as Supersonic Nozzle Materials for Hot Fluorine",
Rev. Sci. Inst. **65**, 3587–3588 (1994). *3 citations, latest citation in 1997.*

*30. J. J. C. Barrett, H. R. Mayne, M. Keil, and L. J. Rawluk,
"Semiclassical Study of Sudden Approximations for Rotationally Inelastic Scattering of Ar+HF",
Can. J. Chem. **72**, 985–994 (1994). *3 citations, latest citation in 2001.*

*29. J. J. C. Barrett, H. R. Mayne, and M. Keil,
"Quantum Effects in Ar+HF Rotationally Inelastic Scattering: A Semiclassical Interpretation",
J. Chem. Phys. **100**, 304–314 (1994). *9 citations, latest citation in 2003.*

*†28. L. J. Rawluk, M. Keil, M. H. Alexander, H. R. Mayne, and J. J. C. Barrett,
"Quantum Effects in the Inelastic Scattering of HF and DF by Argon",
Chem. Phys. Lett. **202**, 291–296 (1993). *18 citations, latest citation in 2003.*

*27. M. Keil, L. J. Rawluk, and T. W. Dingle,
"Anisotropic Repulsive Potential Energy Surfaces from Hartree–Fock Calculations for $HeCO_2$ and HeOCS",
J. Chem. Phys. **96**, 6621–6628 (1992). *11 citations, latest citation in 2005.*

*26. Y. B. Fan, L. J. Rawluk, Y. Apelblat, and M. Keil,
"Effect of Velocity on Saturation Behaviour for HF Molecular Beams",
J. Opt. Soc. Am. B **8**, 1218–1225 (1991). *3 citations, latest citation in 1997.*

*†25. L. J. Rawluk, Y. B. Fan, Y. Apelblat, and M. Keil,
"Differential Cross Sections for Rotationally State–Resolved Inelastic Scattering of HF by Ar",
J. Chem. Phys. **94**, 4205–4218 (1991). *25 citations, latest citation in 2001.*

*†24. M. Keil, L. J. Danielson, and P. J. Dunlop,
"On Obtaining Interatomic Potentials from Multiproperty Fits to Experimental Data",
J. Chem. Phys. **94**, 296–309 (1991). *33 citations, latest citation in 2004.*

*23. L. J. Rawluk and M. Keil,
"Use of a Chemical Laser for Molecular–Beam Scattering Experiments",
J. Opt. Soc. Am. B **6**, 1278–1283 (1989). *5 citations, latest citation in 1997.*

*22. M. Keil, L. J. Danielson, U. Buck, J. Schleusener, F. Huisken, and T. W. Dingle,
"The HeNe Interatomic Potential from Multiproperty Fits and Hartree–Fock Calculations",
J. Chem. Phys. **89**, 2866–2880 (1988). *20 citations, latest citation in 2004.*

*21. L. J. Danielson, M. Keil, and P. J. Dunlop,
"Anisotropic Intermolecular Potentials for HeC_2H_2, HeC_2H_4, and HeC_2H_6, and an Effective Spherical Potential for $HeCHF_3$ from Multiproperty Fits",
J. Chem. Phys. **88**, 4218–4227 (1988). *27 citations, latest citation in 2003.*

*20. M. Keil and L. J. Danielson,
"Sensitivity of Experimental Measurements in Fitting Interatomic Potential Energy Curves",
Can. J. Phys. **66**, 159–163 (1988). *2 citations, latest citation in 1991.*

*19. L. J. Danielson and M. Keil,
"Interatomic Potentials for HeAr, HeKr, and HeXe from Multiproperty Fits",
J. Chem. Phys. **88**, 851–870 (1988). *40 citations, latest citation in 2001.*

*†18. L. J. Danielson, K. M. McLeod, and M. Keil,
"Damping of Total Differential Cross Sections: Observations and Empirical Anisotropic Potentials for HeC_2H_2 and HeOCS",
J. Chem. Phys. **87**, 239–248 (1987). *38 citations, latest citation in 2005.*

*†17. M. Keil and G. A. Parker,
"Empirical Potential for the $He+CO_2$ Interaction: Multiproperty Fitting in the Infinite–Order Sudden Approximation",
J. Chem. Phys. **82**, 1947–1966 (1985). *36 citations, latest citation in 2003.*

*16. H. R. Mayne and M. Keil,
"Rotationally Inelastic Collisions Studied Using Model Potential Energy Surfaces. 1. Polarization and Rainbow Effects and Their Dependence on the Attractive Well",
J. Phys. Chem. **88**, 883–891 (1984). *21 citations, latest citation in 2003.*

15. G. A. Parker, M. Keil, and A. Kuppermann,
"Scattering of Thermal He Beams by Crossed Atomic and Molecular Beams. V. Anisotropic Intermolecular Potentials for $He+CO_2$, N_2O, and C_2N_2",
J. Chem. Phys. **78**, 1145–1162 (1983). *27 citations, latest citation in 1998.*

12. D. Ettinger, K. Honma, M. Keil, and J. C. Polanyi,
"Rotationally Inelastic Scattering from Surfaces. HF(g)+LiF(001)",
Chem. Phys. Lett. **87**, 413–416 (1982). *66 citations*

*11. M. Keil and H. R. Mayne,
"Classical Dependence of Polarization on Potential Energy Surface in Rotationally Inelastic Collisions",
Chem. Phys. Lett. **85**, 456–460 (1982). *6 citations*

10. J. A. Barnes, M. Keil, R. E. Kutina, and J. C. Polanyi,
"Energy Transfer as a Function of Collision Energy. IV. State–to–State Cross Sections for Rotational–to–Translational Energy Transfer in HF+Ne, Ar, and Kr",
J. Chem. Phys. **76**, 913–930 (1982). *64 citations*

9. J. A. Barnes, M. Keil, R. E. Kutina, and J. C. Polanyi,
"Energy Transfer as a Function of Collision Energy. III. State–to–State Cross Sections for Rotational–to–Translational Energy Transfer in HF+Ar",
J. Chem. Phys. **72**, 6306–6308 (1980). *43 citations*

8. J. T. Slankas, M. Keil, and A. Kuppermann,
"Scattering of Thermal He Beams by Crossed Atomic and Molecular Beams. IV. Spherically Symmetric Intermolecular Potentials for He+CH_4, NH_3, H_2O, and SF_6",
J. Chem. Phys. **70**, 1482–1491 (1979). *51 citations*

7. M. Keil, J. T. Slankas, and A. Kuppermann,
"Scattering of Thermal He Beams by Crossed Atomic and Molecular Beams. III. Anisotropic Intermolecular Potentials for He+N_2, O_2, CO, and NO",
J. Chem. Phys. **70**, 541–551 (1979). *101 citations*

6. M. Keil, J. T. Slankas, and A. Kuppermann,
"Scattering of Thermal He Beams by Crossed Atomic and Molecular Beams. II. The He–Ar van der Waals Potential",
J. Chem. Phys. **70**, 482–503 (1979). *17 citations*

5. M. Keil, G. A. Parker, and A. Kuppermann,
"An Empirical Anisotropic Intermolecular Potential for He+CO_2",
Chem. Phys. Lett. **59**, 443–448 (1978). *36 citations*

4. M. Keil, A. Kuppermann, and J. T. Slankas,
"An Accurate Determination of the He–Ar van der Waals Potential",
Chem. Phys. Lett. **59**, 339–345 (1978). *0 citations*

3. M. Keil and A. Kuppermann,
"Scattering of Thermal He Beams by Crossed Atomic and Molecular Beams. I. Sensitivity of the Elastic Differential Cross Section to the Interatomic Potential",
J. Chem. Phys. **69**, 3917–3930 (1978). *12 citations*

2. D. K. Lewis, M. Keil, and M. Sarr,
"Gas Phase Thermal Decomposition of *tert*–Butyl Alcohol",
J. Am. Chem. Soc. **96**, 4398–4404 (1974). *18 citations*

1. D. K. Lewis, M. Sarr, and M. Keil,
"Cyclopentene Decomposition in Shock Waves",
J. Phys. Chem. **78**, 436–439 (1974). *18 citations*

Book Chapters

13. J. W. Hepburn, K. Honma, M. Keil, F. J. Northrup, G. Ogram, J. C. Polanyi, J. M. Williamson, and R. J. Wolf,
"State–Selected Studies of Gas–Surface Encounters",
IUPAC Frontiers of Chemistry, edited by K. J. Laidler (Pergamon, New York, 1982) 413–416.

Conference Proceedings

38. G. A. Parker, S. Crocchianti, and M. Keil,
"Quantum Reactive Scattering for Three Particle Systems Using Hyperspherical Coordinates",
in "Lecture Notes in Chemistry", edited by A. Laganà and A. Riganelli, **75**, 88 (2000).

*31. M. Keil, L. J. Rawluk, M. H. Alexander, H. R. Mayne, and J. J. C. Barrett,
"Rotationally Inelastic Scattering of HF as Probed by a Hydrogen Fluoride Chemical Laser",
in "Laser Techniques for State-Selected and State-to-State Chemistry", edited by J. W. Hepburn, *SPIE Proceedings* **2124**, 28–37 (1994).

14. M. Keil, *with* T. E. Gough, C. Douketis, D. G. Knight, and G. Scoles,
"Contributions to the Faraday Discussions on van der Waals Molecules",
Faraday Disc. Chem. Soc. **73**, 182–183; 286-288; 415–416 (1982).

Patent

*†33. M. Keil, J. H. Young, and K. Copeland,
"Method and Apparatus for Etching Surfaces with Atomic Fluorine",
U. S. Patent #5,597,495 (issued January 28, 1997).

Ultracold Atomic Physics: At Ben-Gurion University, we are working in a unique research environment to develop matter-wave quantum technology. This work is based on the *"atomchip"* wherein techniques from the semiconductor industry are used to trap or guide atoms above a monolithically fabricated microchip. Current work focusses on incorporating two completely new elements into these quantum devices: wires formed by carbon nanotubes from the field of molecular electronics, and optical microresonators as atom traps and detectors from the field of tunable integrated photonics. The resulting quantum devices will find applications in improving time standards, ultrasensitive acceleration sensors for navigation, and, in the longer term, quantum cryptography and quantum computing.

Coherent Control of Chemical Reactions: We have developed and implemented techniques for automatically phase locking nanosecond laser pulses that are generated from independent (and therefore phase-uncorrelated) laser sources. We are exploiting such unique laser pulses for two-photon *vs.* two-photon coherent control experiments currently underway in our laboratory. Our phase-locking procedure requires a very stable interferometer, which also exhibits unusual optical properties. This project is a collaboration between Professor Moshe Shapiro (theory) and myself (experiment). Publication #40.

State-to-State Crossed–Beam Reactive Scattering: We have measured angular distributions for the $F+H_2 \rightarrow HF + H$ chemical reaction in a crossed beam experiment, simultaneously resolving *both* the vibrational *and* rotational states of the reaction product. At the time, these were the first such detailed measurements for any exothermic chemical reaction. Our results are interpretted using accurate quantum dynamical calculations on reliable potential energy surfaces, and show strong evidence for quantum state-specific effects never before observed in reactive scattering. Comparisons between our experimental and fully *ab-initio* quantum theoretical results suggest specific scattering experiments using *para*$-H_2$ and HD, for which we developed suitable molecular beam sources. These comparisons are greatly assisted by collaboration with Prof. Greg Parker (Oklahoma). Publications #35 and 34.

Cold Atomic and Molecular Beams: In a collaboration between University of Oklahoma, Technion, and University of Latvia, we have developed and tested a cold-atom beam source for Rb at 3.5°K. A magnetic octupole field removes fast atoms from a room-temperature thermal distribution, so that only cold atoms remain in the beam. The source does not require any laser or cryogenic cooling and operates at beam intensities that are very high for cold-atom sources. These characteristics make the source particularly well-suited for production of cold *molecular* beams, which the Oklahoma group is developing for the triplet (ground) electronic state of molecular S_2. The source is simple to build and operate and is therefore particularly well-suited for studying ultra-cold atoms and molecules in optical and magnetic traps. Publication #39.

Surface Etching by Atomic Beams: We have measured etching rates for silicon, silicon oxide, and silicon nitride surfaces when exposed to an atomic fluorine beam, designed and built for our studies in chemical dynamics (below). Owing to its uniquely high intensity, the atomic beam can etch these materials at rates comparable to those achieved by plasma techniques. The atomic beam method however produces no solid residue, uses very simple chemistry, does not charge or sputter the surface, and is inherently highly directional. To illustrate the last characteristic, we have etched a $120\,\mu$m$-$deep trench in silicon that is only $1\,\mu$m wide; the sidewall slope is steeper than 1000:1. Unpublished work in collaboration with Prof. Matthew Johnson (Oklahoma) exploits the nano-scale diameters (20-100 nm) of holes in anodic alumina masks to create ordered nano-arrays on silicon, and then uses these masks to create nano-scale dots, pillars, and holes in silicon. All of these features may be of interest to the semiconductor industry. Publication #36.

Atomic Fluorine Beam Source: We developed a uniquely intense and reliable supersonic atomic fluorine beam source for studies in chemical dynamics. Previous such sources could not be operated above 700°C, yielding poor atomic intensities, because of rapid destruction of their pure nickel tubes. Using single-crystal magnesium fluoride tubes, which we manufacture, allows operation up to 1000-1100°C, with no sign of chemical attack. Such temperatures improve dissociation from 5-10% to 90-95%, while allowing higher pressures that yield much better atomic beam characteristics. Our source has been patented, and has been used in several laboratories world-wide. Publication #32 and U. S. Patent (#33).