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**EDUCATION**

Ph.D., Physics, Harvard University, March 2008 (advisor: Gerald Gabrielse)  
A.M., Physics, Harvard University, March 2003  
B.S., Physics *Summa Cum Laude* (Astronomy minor), Case Western Reserve University,  
May 2001

**POSITIONS  
and  
AWARDS**

**NATIONAL INSTITUTE OF STANDARDS AND TECHNOLOGY**, Boulder, Colorado  
NRC Postdoctoral Research Associate (advisor: David Wineland), 2008–present

**HARVARD UNIVERSITY**, Cambridge, Massachusetts  
Graduate student (advisor: Gerald Gabrielse), 2001–2007

National Defense Science and Engineering Graduate (NDSEG) Fellowship, 2001–2004  
Harold T. White Prize “for excellence in the teaching of physics,” 2003  
Certificate of Distinction in Teaching, 2002

**CASE WESTERN RESERVE UNIVERSITY**, Cleveland, Ohio  
Undergraduate student, 1997–2001

Phi Beta Kappa, 2000  
CWRU President’s Scholarship, 1997–2001  
Leslie L. Foldy Award “to the outstanding senior in physics,” 2001  
John Schoff Millis Award “to the senior with the best academic record,” 2001  
Louis K. Levy Prize “for an outstanding junior” (university-wide), 2000  
B. S. Chandrasekhar Prize “awarded upon completion of the junior year to a physics major who  
has demonstrated superior performance,” 2000  
Junior Award of Arts and Sciences “to the junior with the best academic record,” 2000  
Phi Beta Kappa Prize “to a sophomore with the best academic record,” 1999  
Case Alumni Association Junior/Senior Scholarship, 1999–2001  
Peter Witt Scholarship for demonstrating “a vital and active interest in the improvement of life  
in Cleveland,” 1999 & 2000  
Mortar Board, 1999  
National Merit Corporate Scholarship (Union Pacific Corp.), 1997–2001  
Dean’s High Honors, every semester enrolled

**RESEARCH  
EXPERIENCE**

**SUMMARY**

My research has focused on using low-energy atomic-physics techniques for precision measurements and detailed control of quantum systems. As a postdoc, I have used laser interactions with trapped ions to precisely control their quantum states. In the process, I contributed to demonstrating a complete methods set for scalable ion trap quantum information processing, to realizing the first programmable two-qubit quantum processor, and to creating for the first time an entangled state of two separated mechanical oscillators. This work has been called the “Breakthrough of the Year” (*Physics World*), “Science News of the Year” (*Science News*), and one of the “Top 100 Stories of 2009” (*Discover*).

As a graduate student, I contributed to two new measurements of the electron magnetic

moment. The second formed the basis of my Ph.D. thesis. These measurements allowed us to make the best determinations of the fine structure constant with a relative accuracy of 0.37 parts-per-billion, over an order of magnitude smaller uncertainty than the next-best methods. This work was called the “Physics Story of the Year” by the American Institute of Physics’s *Physics News Update*.

### NATIONAL INSTITUTE OF STANDARDS AND TECHNOLOGY

Simple quantum systems such as the harmonic oscillator and the two-level system can be useful tools. For example, the two-level system forms the basis for many quantum information protocols, where it is called a quantum bit or qubit. Trapped ions are among the most advanced candidates for implementing a quantum information processor. Here, the qubits are stored in internal atomic states, and the collective motion of several ions can serve as an information bus for two-qubit gates. I contributed to combining for the first time all the fundamental elements required for scalable quantum computing using qubits stored in internal states of trapped ions. These elements include robust qubit storage, quantum state initialization, readout, and the ability to transfer quantum information between spatially separated locations in the processor. Of the many techniques combined, two were key. First, the quantum information spent the majority of the time robustly stored in a pair of  ${}^9\text{Be}^+$  hyperfine energy eigenstates whose energy separation does not depend on the magnetic field to first order, giving qubit coherence times hundreds of times longer than a typical experiment lasts. Second, the  ${}^9\text{Be}^+$  “qubit” ions were simultaneously trapped with  ${}^{24}\text{Mg}^+$  ions, which could be laser-cooled to sympathetically cool the  ${}^9\text{Be}^+$  ions without disturbing the qubit state.

One particularly interesting result from the early years of quantum information science is that any operation on a multiqubit system can be decomposed into sequences of quantum gates. We decomposed an arbitrary two-qubit unitary operation into a sequence of one and two-qubit gates that could be implemented with the complete methods set above. Such an operation has 15 degrees of freedom, and we implemented our gate sequence such that, given a particular operation, one can calculate 15 real numbers and use them to “program” the quantum processor, which then implements the operation.

The ability to couple two-level systems and harmonic oscillators allows the generation of interesting motional states, including the first creation of separated entangled mechanical oscillators. After entangling the internal states of two  ${}^9\text{Be}^+$  ions in a four-ion  ${}^9\text{Be}^+ - {}^{24}\text{Mg}^+ - {}^{24}\text{Mg}^+ - {}^9\text{Be}^+$  chain, the ions were split into two pairs, each containing one of the entangled  ${}^9\text{Be}^+$  ions. The vibrational modes of each pair are well-described as harmonic oscillators, and laser cooling the  ${}^{24}\text{Mg}^+$  ions allowed several modes to be cooled to their quantum ground state. Additional laser pulses addressed each  ${}^9\text{Be}^+$  ion and mapped its internal state onto one mode of the  ${}^9\text{Be}^+ - {}^{24}\text{Mg}^+$  pair, creating an entangled state of a vibrational mode of one pair and a mode of the other.

### HARVARD UNIVERSITY

Ph.D. THESIS (advisor: Gerald Gabrielse), 2002–2007

#### **Cavity Control in a Single-Electron Quantum Cyclotron: An Improved Measurement of the Electron Magnetic Moment**

Measurements of the electron’s intrinsic magnetic moment (the “ $g$ -value”) probe the electron’s interaction with the fluctuating vacuum. With a quantum electrodynamics calculation, they provide the most accurate determination of the fine structure constant. Given an independent determination of the fine structure constant, such measurements set limits on electron substructure and other extensions to the Standard Model of particle physics.

At Harvard, I contributed to two new measurements of the electron magnetic moment. The second formed the basis of my thesis; at a relative uncertainty of 0.28 parts-per-trillion, it improved upon our first measurement by nearly a factor of three and upon the celebrated 1987 University of Washington measurement by a factor of 15. It yielded a value of the fine structure constant with a relative accuracy of 0.37 parts-per-billion, over an order of magnitude smaller uncertainty than the next-best methods.

The high precision arises from the combination of many useful techniques. A single-electron quantum cyclotron, so-called because a quantum nondemolition measurement resolves the lowest cyclotron and spin levels, is held in a cylindrical Penning trap, whose well-understood cavity-mode structure inhibits spontaneous emission and creates calculable frequency shifts due to electron-cavity coupling. A low temperature (100 mK) narrows the linewidths of the measured frequencies and inhibits stimulated absorption in the cyclotron motion, effectively locking it in the ground state. The signal from the electron's axial motion is fed back as a drive, forming the first single-particle self-excited oscillator and increasing the signal-to-noise. Advances leading to the newest measurement, presented in my thesis, include extending a magnetic field drift-tracking technique to longer timescales and using the electron's cyclotron damping rate as a sensitive probe of the cavity modes.

### CASE WESTERN RESERVE UNIVERSITY

SENIOR THESIS (advisor: Arnold Dahm), 2000–2001

#### **A New Technique for Measuring Isotopic Impurity Diffusion in Solid Helium**

In this thesis, I designed and began construction of an apparatus that used NMR and three orthogonal gradient coils to measure the diffusion of isotopic impurities in solid helium as a probe of the properties of vacancy waves.

### INDEPENDENT RESEARCH

Sonoluminescence (advisors: Harsh Mathur and Kathleen Kash), 1999

I modified a non-working sonoluminescence apparatus and, while waiting for long lead-time materials, simulated the dynamics of a sonoluminescing bubble and found an experimentally-accessible order-to-chaos transition.

Granular matter (advisor: Harsh Mathur), 2000

Using stochastic methods, I modeled the propagation of force down a regular two-dimensional array of particles to examine how an applied force on the first layer changes the force profile at the base.

### **TEACHING and ADVISING**

### HARVARD UNIVERSITY

UNDERGRADUATE SUPERVISION, 2003–2007

As a graduate student, I had the opportunity to supervise five undergraduates during both the summer and regular school year. They worked on various projects related to our quantum cyclotron experiment including characterizing the laboratory vibrations, designing a pump room and vacuum system, and calculating the magnetic field homogeneity and inductance matrix for a new solenoid.

TEACHING FELLOW, 2002

*Principles of Physics: Electricity, Waves, Nuclear Physics (Physics 1b)* (instructor: Eric Mazur)

*Physics 1b* was the second semester of a year-long introductory physics course for students in the life sciences. As a teaching fellow, my responsibilities included co-teaching a section, a moderate amount of question writing and grading, and aiding the instruction during the main lectures, which were taught using an interactive format. The teaching awards mentioned above were for my work in this course.

#### CASE WESTERN RESERVE UNIVERSITY

GetHIP (Get Help-In-Physics) Walk-In Tutoring (advisor: Mano Singham), 2000–2001  
Designed a java applet for *Introduction to Quantum Mechanics (PHYS 331)* (instructor: Kathleen Kash), 2000  
Grader for *Physics and Frontiers I (PHYS 123)* (advanced freshman mechanics, instructor: Robert Brown), 1998  
Grader for *Physics and Frontiers II (PHYS 124)* (advanced freshman E&M, instructor: Charles Rosenblatt), 1999, 2000

#### **PUBLICATIONS and PRESENTATIONS**

#### REFEREED PUBLICATIONS

##### **Realization of a programmable two-qubit quantum processor**

D. Hanneke, J. P. Home, J. D. Jost, J. M. Amini, D. Leibfried & D. J. Wineland  
*Nature Physics* **6**, 13–16 (2010)

##### **Complete Methods Set for Scalable Ion Trap Quantum Information Processing**

Jonathan P. Home, David Hanneke, John D. Jost, Jason M. Amini, Dietrich Leibfried, David J. Wineland  
*Science* **325**, 1227–1230 (2009)

##### **Entangled Mechanical Oscillators**

J. D. Jost, J. P. Home, J. M. Amini, D. Hanneke, R. Ozeri, C. Langer, J. J. Bollinger, D. Leibfried, and D. J. Wineland  
*Nature* **459**, 683–685 (2009)

##### **New Measurement of the Electron Magnetic Moment and the Fine Structure Constant**

D. Hanneke, S. Fogwell, and G. Gabrielse  
*Physical Review Letters* **100**, 120801 (2008)

##### **New Measurement of the Electron Magnetic Moment Using a One-Electron Quantum Cyclotron**

B. Odom, D. Hanneke, B. D'Urso, and G. Gabrielse  
*Physical Review Letters* **97**, 030801 (2006)

##### **New Determination of the Fine Structure Constant from the Electron $g$ Value and QED**

G. Gabrielse, D. Hanneke, T. Kinoshita, M. Nio, and B. Odom  
*Physical Review Letters* **97**, 030802 (2006)  
An error by our theory collaborators was fixed in *Ibid.* **99**, 039902(E) (2007)

##### **Single-Particle Self-Excited Oscillator**

B. D'Urso, R. Van Handel, B. Odom, D. Hanneke, and G. Gabrielse  
*Physical Review Letters* **94**, 113002 (2005)

**OTHER PUBLICATIONS AND PRESENTATIONS**

Southwest Quantum Information and Technology (SQuInT) 2010, Santa Fe, NM  
Contributed talk: **Putting the pieces together: Recent progress with trapped ions at NIST**

SPIE Photonics West 2010, San Francisco, CA  
Invited talk: **Recent progress in quantum information processing with trapped ions**

Boulder Laboratories Postdoctoral Poster Symposium 2009, Boulder, CO  
Poster presented: **Universal quantum control of two qubits**

APS Division of Atomic, Molecular, and Optical Physics (DAMOP) 2009, Charlottesville, VA  
Contributed talk: **Sympathetic cooling and trapped-ion quantum logic (Repeated two-qubit logic gates with scalable techniques)**

David Hanneke, J. D. Jost, J. P. Home, J. M. Amini, R. Ozeri, C. Langer, J. J. Bollinger, D. Leibfried, D. J. Wineland

Gordon Research Conference 2008 (Quantum Information Science), Big Sky, MT  
Poster presented: **Distribution of entanglement in an ion trap array**

International Conference on Atomic Physics (ICAP) 2008, Storrs, CT  
Proceedings: **More Accurate Measurement of the Electron Magnetic Moment and the Fine Structure Constant**

D. Hanneke, S. Fogwell, N. Guise, J. Dorr, and G. Gabrielse  
In R. Côté, P. L. Gould, M. Rozman, W. W. Smith (eds.), *Pushing the Frontiers of Atomic Physics: Proceedings of the XXI International Conference on Atomic Physics*  
World Scientific, pp. 46–55, 2009

**Precision pins down the electron's magnetism**

G. Gabrielse and D. Hanneke  
*CERN Courier*, October 2006, pp. 35–37

International Conference on Atomic Physics (ICAP) 2006, Innsbruck, Austria  
Poster presented: **New Measurement of the Electron Magnetic Moment and Fine Structure Constant**

Proceedings: **New Measurement of the Electron Magnetic Moment and Fine Structure Constant**

G. Gabrielse and D. Hanneke  
In C. Roos, H. Haffner, R. Blatt (eds.), *Atomic Physics 20: XX International Conference on Atomic Physics – ICAP 2006*  
AIP Conference Proceedings, Vol. 869, pp. 68–75, 2006

Conference on the Intersections of Particle and Nuclear Physics (CIPANP) 2006, Puerto Rico  
Proceedings: **New Measurement of the Electron Magnetic Moment and Fine Structure Constant**

G. Gabrielse and D. Hanneke  
In T. Liss (ed.), *Intersections of Particle and Nuclear Physics: 9th Conference CIPANP 2006*  
AIP Conference Proceedings, Vol. 870, pp. 328–332, 2006

Lepton Moments International Symposium 2006, Cape Cod, MA  
Poster presented: **New Measurement of the Electron Magnetic Moment and Fine Structure Constant**

International Conference on Atomic Physics (ICAP) 2004, Rio de Janeiro, Brazil

Poster presented: Toward an Improved Electron  $g-2$  Measurement

**SECONDARY REPORTS ON THE TRAPPED-ION WORK**

**Breakthrough of the Year**, *Physics World*, posted online December 21, 2009

**2009 Science News of the Year: Matter & Energy**, *Science News*, January 2, 2010, Vol. 177 #1, p. 24

**Top 100 Stories of 2009 – #40**, Elizabeth Svoboda, *Discover*, January/February 2010, p.49

**First Programmable Quantum Computer Created**, Laura Sanders, *Science News*, December 19, 2009, Vol. 176 #13, p. 13

**First universal programmable quantum computer unveiled**, Colin Barras, *New Scientist* online, November 15, 2009

**The pieces put together**, *Nature Physics* **5**, 622 (2009)

**Mechanical Systems All Tangled Up**, Laura Sanders, *Science News*, July 4, 2009, Vol. 176 #1, p.8

**Physics Update**, *Physics Today*, July 2009, 22

**Entanglement goes mechanical**, Rainer Blatt, *Nature* **459**, 653–654 (2009)

**Quantum Computing with Ions**, Christopher R. Monroe and David J. Wineland, *Scientific American*, August 2008, 64–71

**SECONDARY REPORTS ON THE  $g$ -VALUE WORK**

**The Physics Story of the Year for 2006**, P. Schewe, B. Stein, and D. Castelvechi, *Physics News Update* 804, December 5, 2006

**Plumbing the Electron's Depths**, P. Schewe and B. Stein, *Physics News Update* 783, July 5, 2006

**A More Precise Fine Structure Constant**, D. Kleppner, *Science* **313**, 448–449 (2006)

**A Finer Constant**, A. Czarnecki, *Nature* **442**, 516–517 (2006)

**Gyromagnetic Ratio of a Lone Trapped Electron is Measured to Better than a Part Per Trillion**, B. Schwarzschild, *Physics Today*, August 2006, 15–17

**Precision pins down the electron's magnetism**, G. Gabrielse and D. Hanneke, *CERN Courier*, October 2006, 35–37

**The Magnet in the Electron**, G. Gabrielse, *Physics World*, February 2007, 32–36

**In Constant Search of 'alpha'**, M. Inman, *New Scientist* **2568**, 40–43 (2006)