The
Quantum Times

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Newsletter of the Topical Group on Quantum Information

American Physical Society

Inside this issue

The Bachelor in Quantum Information Science and why it won't happen

Jan Florjanczyk

Doubtlessly, quantum information has benefited by assimilating members trained in a wide array of sciences, predominantly physics, mathematics and computer science. However, with (im)perfect 20/20 hindsight, we can always speculate on what a specialized undergraduate degree in quantum information science may look like.

The transition from the undergraduate curriculum-led lifestyle to the graduate research-led one can be turbulent when headed for quantum information. Likely, students come from at most two of the above three constituent areas. As a graduate student you can always play the game of "picking things up as you go" but this is not a mentality that scales well to the average freshman. Learning to trace results up through their parent papers or even searching the Internet using correct terminology is tough to learn in a lecture hall. To students starting out, the field of knowledge ahead of them seems of an absolutely overwhelming size. Thus, to make a quantum information scientist from scratch we have to examine what is essential and what is superfluous in an undergraduate curriculum.

Personally, I come from a background in physics and mathematics so I can only speak from this vantage point. However, my recent foray into computer science has shown me very clearly what it is that I lacked (or likely still lack) in that field. Altogether, I'm looking to distill in this article the essentials from my undergraduate degree that now support my studies in

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Giving Quantum Information Science the Old College Try

Mark M. Wilde

The senseis and gurus of quantum information science (QIS) have been training generations of quantum information scientists for some years now, through advanced courses at select research-oriented institutions around the world. **John Preskill** of **Caltech** was one of the first pioneers in this area, introducing several graduate-students-and-postdocs-turned-professors to the topic through his classic Physics 219 Course on Quantum Computation and his accompanying lecture notes. Since that course, many advanced graduate courses have appeared at institutions such as **Cal Berkeley**, **MIT**, **Stanford**, **Southern California**, **Waterloo**, and **McGill**, to name only a few.

The teachers of these courses have dispensed the knowledge and tricks of QIS to energetic graduate students and have played a major role in the blossoming of the field to what it has become today. Some might even say that this dispensation has catapulted QIS to become "mainstream" so that more and more we find in casual conversation with friends and acquaintances that they have heard the news of the quantum information revolution. The fact that so many incoming graduate students in physics and computer science have caught the "quantum fever" may "turn off" some of the more nostalgic contributors, for fear that QIS is losing its cult status and becoming too commercialized. On the other hand, many of us find it exciting that students are so interested to embrace QIS.

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quantum information.

The core of the mathematics required is a basic understanding of probability and a very strong foundation of linear algebra. With only these tools we already find ourselves with enough framework to begin proving some rudimentary results. However, a course in probability at the undergraduate level is likely to focus on a survey of distributions and characteristic functions. We can make due with Bayes' rule and Markov's inequality in our curriculum. Alongside a short survey of constructions such as cyclic groups, a thorough understanding of linear algebra plays the central role in quantum information theory. More particularly, it is essential to grasp tensor product structure early on and this is very easily overlooked in a math program. Also, I would urge to prescribe the full run of mathematical analysis courses. Knowing about metric spaces and measure theory has proven repeatedly useful. Finally, group theory, complex variables and PDEs belong in this program as well, but a thorough treatment is not necessary as a student can still follow along most of the material without them.

A "classical" physics program is also a little ill-at-ease in the shaping of a quantum information scientist. Newtonian and (I would claim) Hamiltonian mechanics simply never appear. Classical electromagnetism and optics can lead to quantum optics so perhaps they should be included. But what else is left? Statistical mechanics and quantum mechanics, both of which tend to play off each other a little. Quantum mechanics itself deserves the most attention. The practice is to divide a large survey of quantum mechanics into two or three successive courses. These begin with introductory topics such as the Schroedinger equation, potential wells, eigenstates and values (all strictly in one spatial dimension). Next, students find themselves solving the equations of the hydrogen atom. For this they need spin operators, variational methods and most importantly: perturbation theory. Density operators may make a brief appearance in the third course and although Bell measurements may be mentioned, the POVM formalism is generally ignored. The process of teaching successively complicated mathematical methods to support successively complicated physical scenarios makes sense to enforce a more phenomenological understanding of physics. However, this is the long way to get to what quantum information science really needs, that is, a foundational understanding that leads to the circuit model necessary for algorithm development.

Enter the third science. The most important computer science concepts I could have had coming into quantum information are definitely algorithm design and complexity theory. I am unashamed to say that as a student formerly bound for something closer to the study of general relativity, the word "algorithm" was once terrifying. Even the design of the simplest

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Yet, for the most part, the dispensation of this knowledge occurs at the graduate level or at an advanced undergraduate level, so that the learners of the quantum secrets live at the higher echelons of student life. But here and there, a few institutions have been introducing QIS to the freshest and youngest of faces and minds—some even to freshmen! (gasp!) In this article, we discuss a few of these undergraduate courses and some textbooks that are useful for the undergraduate level.

Introduction at the earlier levels could be beneficial for students who might eventually seek a research-oriented career. After all, the mathematics required to learn quantum theory for quantum information is linear algebra and probability theory! (At least we can tell that to the incoming students to encourage them.) I can even remember when I was fresh out of my undergraduate experience and reviewing linear algebra that **Gilbert Strang** started talking about the importance of matrix diagonalization in quantum mechanics in his book *Linear Algebra and Its Applications*. Fascinated by his discussion, I kept reading more and more about quantum mechanics and information, until I decided to pursue research in this fascinating field. So, I tend to think that there is nothing wrong with early exposure, and some courses that we discuss below are bringing this exposure to ever younger crowds.

The most striking example of an undergraduate course is one delivered to freshmen, named *Mysteries of the Quantum World*. **Lev Kaplan** and **Dmitry Uskov** of **Tulane University** have been offering this course for the past two years, in an effort to build up the new Engineering Physics degree program down in NOLA, the "Big Easy." The course features an introduction to concepts in quantum information such as BB84 quantum key distribution and quantum error correction. Students complete homework that include computer simulations, and they write an essay on a topic in quantum information. One of the more exciting aspects of the course is a field trip to LIGO (Laser Interferometer Gravitational Wave Observatory) located in Livingston, Louisiana and operated by **Caltech** and **MIT**. There, the students learn about real-world, albeit exotic, applications of quantum mechanics in the detection of gravitational waves. Many of the students who took this course are now majoring in mathematics, engineering physics, and physics.

As part of its ongoing effort in building its QIS empire, the **University of Waterloo** is now offering a full-featured graduate program in QIS, inching ever close to a full graduate degree purely in quantum information. The introductory course CO 481/CS 467/PHYS 467, crosslisted to combinatorics and optimization, computer science, and physics students, is an undergraduate course. **Andrew Childs** teaches it, covering standard topics such as the quantum circuit

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algorithms is not a "pick it up as you go" affair. It is just as practiced an art as any problem solving in mathematics and physics. The computer science component of this curriculum must also provide a course in information theory. This is essential because although you can sit down and read the classical background from Mike and Ike, there's no way to develop intuition without practice.

The only missing piece is a course (or a few courses) in quantum information proper. Any of the textbooks suggested by Mark Wilde (see the parallel column to the right) could be suitable. However, if you try to solidify a point at which to teach quantum information with respect to its math, physics, and computer science requisites, you cannot do so honestly until very late in the program. For example, it is difficult to introduce the Hadamard gate without quantum states, which in turn cannot be introduced until a solid understanding of linear algebra is established. Whichever way you go about it, you would always end up pushing the quantum information content further and further back in the program until you reached something resembling more of a B.Sc. (Hons. in QIS) than a true Bachelor in Quantum Information Science.

Perhaps it is fortunate that diving immediately into quantum information out of high school is impossible. Students in their undergraduate years change direction very often. A program specific to quantum information would be restricting since it would provide only background required for QIS and lack in the overlap required for students to move subjects. Quantum information science also gains much by attracting diversely educated students. Every math, physics, and computer science course that was not mentioned here plays a vital role in shaping the individuals who make up the QIS community. Nor should it be forgotten that chemistry and engineering are also contributors to the rapidly spreading pool. All in all, a Bachelor in Quantum Information Science would accomplish nothing more than guide a student through the history of quantum information science but sadly leave them short-handed for research in the field.

For now we can just wait until the game-changer: a fully functioning quantum computer. At that point we can start to visit the exciting realm of the Bachelor in Quantum Engineering.

***Jan Florjanczyk** is a Master's student in computer science at McGill university. His studies and research focus on quantum information theory under the tutelage of Prof. Patrick Hayden. He muses about black holes and baking on:*

www.sublimesuperlemon.com.

SUBLIME SUPERLEMON

Wilde, continued

model, computational complexity, quantum algorithms, and quantum error correction. The book that he uses is one produced "in house," from **Phillip Kaye**, **Raymond Laflamme**, and **Michele Mosca** and entitled *An Introduction to Quantum Computing*. Certainly this course will help build up Waterloo's effort by introducing advanced undergraduates to the topic.

Two textbooks bring quantum information concepts to the undergraduate level. The first of these is *Protecting Information: From Classical Error Correction to Quantum Cryptography* by **Susan Loepp** and **William Wootters**. This text covers some basic ideas in cryptography and quantum mechanics and shows how to unify the concepts for quantum cryptography. The last chapter features an introduction to quantum computing that covers some of the essential concepts such as factoring and search. A more recent book that is amenable for those with computer science backgrounds is **David Mermin's** *Quantum Computer Science: An Introduction*. Mermin developed the book over the course of teaching it for many years to a diverse group of undergraduates, graduates, and faculty at **Cornell University**. He assumes little background, other than some familiarity with linear algebra and probability, and goes far with this approach. Many have suggested that this book might become the standard text for the topic, perhaps even displacing the heralded quantum computing "bible" Mike and Ike's *Quantum Computation and Quantum Information* (say it ain't so!).

A forthcoming undergraduate textbook, by **Charles Bennett**, **David DiVincenzo**, and **William Wootters**, entitled *Quantum Information Theory* will be part of Springer's Undergraduate Texts in Contemporary Physics Series. It is slated to be around 100 pages (and due in January 2010!) and should be a welcome introduction from some of the experts who laid the foundations of QIS. It will cover the basic ideas of the information capacities of quantum channels and error correction schemes for quantum computers.

These and other efforts should help disseminate the knowledge of the quantum to ever younger and eager students. Perhaps you will be less surprised the next time that you are out at a bar or a party to learn that someone has a bit more than the foggiest notion of what you do when you inform them that you are a quantum information scientist.

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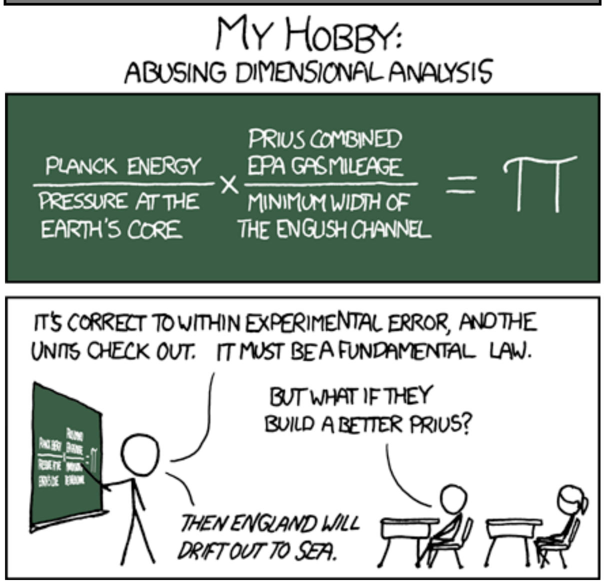
THE LIGHTER SIDE

FROM XKCD.COM BY RANDALL MONROE



Quantum Prospects: A Survey

How likely are we to ever make a quantum computer? What is the biggest challenge? Professor Chandralekha Singh at the University of Pittsburgh, a researcher in physics education, is conducting a survey of experts and non-experts in the field of quantum information. She would like to catalogue and correlate answers with the degree of familiarity in the field. What are the biggest concerns from the perspective of experts, and how do these concerns compare with those of non-experts?

If you are interested, please navigate to this website to fill out the short questionnaire: http://tinyurl.com/quantum-prospects.

Stay tuned for the results!

Bits, BYTES, *and Qubits*

QUANTUM NEWS & NOTES

Google + D-Wave = Bad news for libertarians

Google and D-Wave have recently partnered on the development of enhanced imaging capabilities for Google's StreetView and other imaging applications. Google's approach utilizes the D-Wave C4 Chimera chip running adiabatic quantum computing algorithms pioneered by Eddie Farhi at MIT to train a detector to pick out a car or a truck from the background of an image. In other words, given, as an example, a StreetView shot of, say, a house with a car in the driveway, the detector is able to locate the car and draw a box around it. Note that Google simply uses the chip to train the algorithm. Once it is trained it can run on any computer. This allowed Google and D-Wave to bring a demo with them to QIP 2010 in Zürich where yours truly received a demonstration over lunch one day with a webcam picking out Matchbox cars set in front of varying backgrounds. While some still question whether D-Wave's chips are truly quantum, Google has taken the attitude that the speed-up the C4 Chimera offers over classical chips is so dramatic that the exact nature of the chip is irrelevant. This, of course, is bad news for libertarians like myself who are already creeped out by StreetView.

Ultra-cold quantum chemistry - brrr...

Physicists at JILA (which used to stand for Joint Institute for Laboratory Astrophysics but now apparently is no longer an acronym) at the University of Colorado at Boulder have, for the first time, observed chemical reactions near absolute zero while also controlling the reaction rates of the chemical processes. The group, led by Deborah Jin, was able to simultaneously control molecular dynamics on a quantum level while also controlling the molecules' internal states such as vibration, rotation, spin, etc. The experiments were performed with a gas containing up to 1 trillion molecules per cubic centimeter (sounds like a lot but it really isn't) at temperatures of a nano-Kelvins above absolute zero. Each molecule consists of a negatively charged potassium atom and a positively charged rubidium atom so they can be controlled with electric fields. By measuring how many molecules are lost over time from a gas confined inside a laser-based optical trap, at different temperatures and under various other conditions, the group was able to observe heat-producing chemical reactions.

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The Quantum Times is a publication of the Topical Group on Quantum Information of the American Physical Society. It is published four times per year, usually in March, June, September, and December, though times may vary slightly.

Contributions

Contributions from readers for any and all portions of the newsletter are welcome and encouraged. We are particularly keen to receive

- **op-ed pieces and letters** (the APS is *strongly* encouraging inclusion of such items in unit newsletters)
- **books reviews**
- **review articles**
- **articles describing individual research** that are aimed at a broad audience
- **humor** of a nature appropriate for this publication

Submissions are accepted at any time. They must be in electronic format and may be sent to the editor at idurham@anselm.edu. Acceptable forms for electronic files (other than images) include LaTeX, Word, Pages (iWork), RTF, PDF, and plain text.

Editorial policy

All opinions expressed in *The Quantum Times* are those of the individual authors and do not represent those of the Topical Group on Quantum Information or the American Physical Society in general.

Spin-control of single electrons

Researchers at Princeton and UC-Santa Barbara have discovered a way to control the spin of a single electron with a magnetic field without disturbing neighboring electrons. The team was led by Jason Petta of Princeton. Their method traps one or two electrons in microscopic corrals created by applying voltages to tiny electrodes which gives them an ability to control spin orientation. In addition to being able control a single electron, the method also allows the spin of the electron to be tweaked in approximately one-billionth of a second which is one-hundred times faster than electron spin resonance methods. The method is a bit analogous to holographic techniques where, instead of aligning the phases of two beams of light, the phases of two quantum spin waves are aligned. Of course this breakthrough has huge implications for semiconductor-based quantum computing. The next step will be to realize control of two adjacent electrons, allowing them to interact.

-ITD

Past, present, and future intersect in Zürich

Ian T. Durham

QIP 2010 was held recently in Zürich, Switzerland at the legendary ETH-Zürich, whose hallowed halls were once walked by the likes of Pauli, Einstein, Stern, and Bloch. This year I had the privilege to attend and found it to be a very stimulating and interesting meeting. Since podcasts of all the talks, along with slides from the tutorial sessions and a photo gallery (including one or two unflattering shots of my growing bald spot), may be found online (see http://www.qip2010.ethz.ch/), I will forego the usual summary in favor of a description of some of the physics-related historical sight seeing that I did while there.

Having done a fair bit of traveling lately and being generally tired of hotels, I decided to try something different. Todd Brun (USC) and I found an apartment to rent for the week that was walking distance from the downtown campus of ETH where the conference was held. It was also on a tram line that came directly from the airport (convenient!). The apartment was nice, very clean and modern, though it was a bit like staying in an Ikea showroom.

The conference was held in the old central campus of ETH that is next door to the downtown campus of Universität Zürich. If you've never been, I highly recommend visiting at some point, though not all of the

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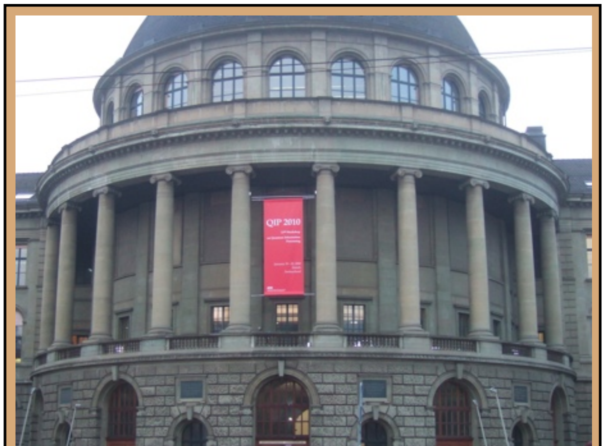
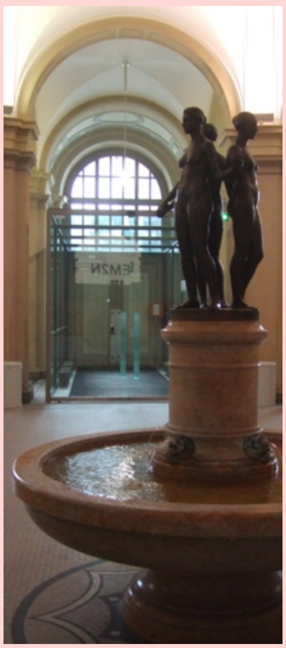


ETH main building; Photo: I.T. Durham



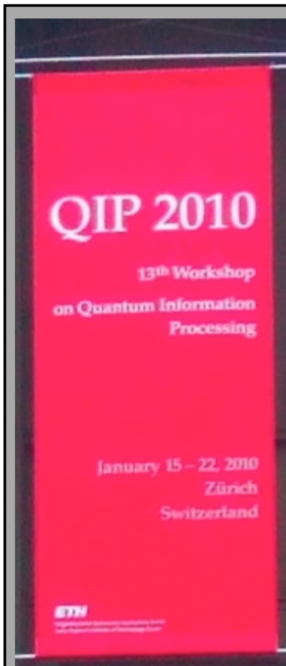
Fountain inside ETH main building; Photo: I.T. Durham

science departments are housed on this campus. The main building was quite opulent and included marble fountains and sculptures alongside very modern amenities. Personally I found the juxtaposition of the two quite interesting. For instance, the heavy wooden doors leading into the building, that looked to be well over a century old, were nevertheless automated.

Knowing the tremendously rich quantum heritage of the area, I took the one scheduled open afternoon of the workshop to do some historical sight-seeing. It was my intent to find at least one of Einstein's homes, James Joyce's grave ("Three quarks for Muster Mark!"), Wolfgang Pauli's grave, and, just for fun, Liechtenstein (hey, why not?). I was joined in my quest by fellow quantum-blogger Suzanne Gildert (Birmingham) of Physics & Cake fame who was the only person who didn't think I was nuts. Of all the things we set out to find, the one thing we *didn't* find that day was Liechtenstein (more on that later - how does one not find an entire country?).

In any case, finding Joyce's grave was relatively easy since it's a well-known site. All of Einstein's residences in the city have been documented by the Stadtarchiv Zürich and it is a fairly simple task to look them up. In fact the city provides photographs and maps for each of the locations (though it is only provided in German - URLs to the sites are given at the end of this article).

Pauli's grave proved a bit more of a challenge. There is very little in the way of online information about the location of Pauli's grave (at least until I came along...). Being the persistent little bugger that I am, I contacted John Rigden of the AIP Center for History of Physics who, along with Roger Stuewer, had written an article in which he had mentioned visiting the grave back in the 1980s after having gotten in touch with Pauli's widow (who was delighted that anyone would want to visit the grave). John couldn't remember exactly where it was, but he remembered it was in the suburb of Zollikon and that the cemetery was known simply as "Zollikon cemetery." Armed with that information and Google Maps, I was able to locate the cemetery itself which was tucked away in a residential neighborhood not far from the hospital in which Pauli died (in room 137, of course).



QIP Banner; Photo: I.T. Durham

Upon our arrival, we found the cemetery to be larger than we had expected and we were unable to locate the grave ourselves. Neither of us spoke German (though I did have a dictionary and phrase-book with me). Nevertheless, we came upon some workers laying flowers on some of the graves - one older gentleman and one younger. We managed to communicate the fact that we were looking for Wolfgang Pauli. The older guy had no idea who we were talking about, but the young guy knew exactly where the grave was (and it is tucked away so we never would have found it on our own).

Interestingly enough, buried right next to Pauli is mathematician Heinz Hopf. Hopf is best known for the development of Hopf algebras which are a form of noncommutative algebra. Most quantum groups are actually some kind of Hopf algebra.

Neither Hopf's nor Pauli's headstones was as impressive as the bronze statue of Joyce, but neither were they neglected. They weren't quite as visually impressive as others I've seen, but they seemed to be relatively fitting tributes.

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After visiting Hopf's and Pauli's graves, we set out to find Liechtenstein. Now, normally I am excellent with directions. However, the rental car company did not provide me with an adequate map and the GPS system in the car was so bare-bones that it was utterly useless. Nonetheless, I knew approximately where it was and that it was an hour southeast of Zürich. I figured that, being an entire country, we were bound to see signs for it the closer we got.

Well, I was wrong. We saw signs for Austria and Germany, but none for Liechtenstein. We were still driving well after sunset when we finally gave up and turned around. Lo and behold, upon returning to the apartment that night and looking it up on the web, I discovered that the exit off of the highway that we used to turn around was the first exit for Liechtenstein which was 4 miles up the road. We had been 4 miles from an entire country and there was absolutely no evidence it even existed. The line from *Rosencrantz and Guildenstern Are Dead* about England being a "conspiracy of cartographers" began playing over and over again in my head.

Did I mention how utterly persistent I am? Having burned out from the intensity of the workshop by midday on Friday (and considering it was an absolutely gorgeous day), I rented another car and, alone this time (maybe Suzanne finally figured out just how nuts I really am), drove to Liechtenstein which turned out to be a bit anti-climatic. Since there wasn't much in the way of physics-related tourism in the tiny country that is reputedly the last vestige of the Holy Roman Empire, I will leave that part out of my narrative.

However, armed with some free time (considering one can see all of Liechtenstein in about an hour), I headed up into the mountains to find one more grave - that of the late CalTech astronomer Fritz Zwicky whose family had come from Mollis, Switzerland. Zwicky is best known for his astronomical discoveries at Mount Wilson Observatory, but, along with Walter Baade, he also first proposed the notion of a supernova and the fact that the remnant was a neutron star. Zwicky also developed a generalized form of what is now known as "morphological analysis."

Zwicky had apparently been buried in Mollis which was a tiny town nestled on the slopes of a mountain. Considering the town's size and the fact that it only had one cemetery, I figured finding old curmudgeonly Fritz wouldn't be too difficult.

Well, I was wrong. Again. At first I thought it might be an *easier* task than I had thought when, upon entering the town, I noticed a shop called Blumen Zwicky (that would be Zwicky's Florists). This seemed promising until I entered the cemetery. Once again I had come unprepared figuring that I had a rough idea of when Fritz had died (sometime in the 1970s or 1980s) and figuring there couldn't be that many "Fritz Zwickys," at least of roughly the same age. Of course there were *several* people by that name in the cemetery *all of whom died in the '70s and '80s*! Not knowing which was the correct one, I snapped photographs of several only the find out later that I had not gotten a photo of the one I was looking for.

Statue of James Joyce by his grave;
Photo: I.T. Durham

At any rate, after visiting Fritz' home town, I drove further up into the mountains in order to get a feel for the countryside. It was gorgeous, of course, and was a pleasant end to my stay in Zürich. It turned out not to be the end of the story, however.

A few weeks after my return home I received in the mail a speeding ticket (entirely in German) for driving 59 kph (37 mph) in a 50 kph (31 mph) zone. Yes, apparently Switzerland has speed cameras (which the rental car company had not warned me about) and they are set to give tickets at a mere 5 kph (3.1 mph) over the speed limit. Mind you, I always drive the speed of traffic, figuring that the locals must know what they're doing. Did I mention that Zürich residents seemed a bit like New Yorkers? This was particularly interesting in light of my speeding ticket. More than once I was honked at for driving too slowly or not reacting quickly enough to a green light. Apparently Zürich residents must assume these tickets are merely part of their commuting costs.

Regardless of this glitch, it was an enjoyable trip and the workshop was excellent. Next year's workshop will be in Singapore (alas, that is a bit beyond my budget, though in 2012 it will be in Montréal which is just "up the road a piece" as we say in Maine).

Ian T. Durham *is the editor of this rag. Please lodge all complaints with him. When he is not looking for dead people, he is Associate Professor and Chair of the Department of Physics and Director of the Computational Physical Sciences Program at Saint Anselm College in Manchester, New Hampshire. He lives on the coast of Maine with his wife, two kids, dog, and a tankful of guppies. He blogs about life, liberty, and the pursuit of quantumness at* http://quantummoxie.wordpress.com.

QUANTUM MOXIE
life as a quantum mechanic

Resources:

Stadt Zürich site with pictures, addresses, and maps of every place Einstein lived in the city (in German):
http://www.stadt-zuerich.ch/prd/de/index/stadtarchiv/bilder_u_texte/texte_zu_albert_einstein/die_wohnhaeuser_alberteinsteinsinzuerich.html

Stadt Zürich site with details of the above residences:
http://www.stadt-zuerich.ch/prd/de/index/stadtarchiv/bilder_u_texte/texte_zu_albert_einstein/albert_einstein_in_zuerich.html

A custom Google map of physics-related historical sites in and near Zürich:
http://maps.google.com/maps/ms?ie=UTF8&t=h&hl=en&msa=0&msid=118316920445135651458.00047769b3c64ec482113&z=10






Clockwise from bottom left: Church in Mollis, Switzerland next to which Fritz Zwicky is buried; Universität Zürich; one of Einstein's former residences; Pauli's headstone; Zürich central library; Hopf's headstone. All photos: I.T. Durham

New graduate program

The University of Waterloo, in conjunction with the Institute for Quantum Computing, the Departments of Applied Mathematics, Chemistry, Combinatorics & Optimization, Electrical & Computer Engineering, and Physics & Astronomy, and the David R. Cheriton School of Computer Science, is offering a new collaborative graduate program in Quantum Information that leads to MMath, MSc, MASc, and PhD degrees. Students complete the requirements of both their home program and the specific requirements of the quantum information (QI) program to achieve the special QI designation. (e.g., MMath in Computer Science (Quantum Information), PhD in Chemistry (Quantum Information), MASc in Electrical and Computer Engineering (Quantum Information)).

MMath, MSc, and MASc students will receive a strong and broad foundation in quantum information science, coupled with knowledge and expertise from their home program. This will prepare them for the workforce or further graduate studies and research leading towards a PhD.

PhD students will be prepared for careers as scholars and researchers, with advanced expertise in quantum information science, along with the focus of their home program. The new program is designed to provide knowledge of quantum information, including theory and implementations, their home program discipline, and also developed advanced expertise in their particular research area within quantum information.

At present, IQC has a critical mass of expertise in several major research areas within quantum information, including:

- Quantum Algorithms and Complexity
- Quantum Information and Communication
- Quantum Cryptography
- Quantum Error Correction and Fault-tolerance
- Spin-based implementations
- Quantum Optics-based implementations
- Nanoelectronics-based implementations.

New state-of-the-art building

In line with the expansion goals of the Institute for Quantum Computing, a new, state-of-the-art building for the Institute is on the way, as part of the Mike and Ophelia Lazaridis Quantum-Nano Centre (QNC). The building will contain a new fabrication and metrology facility, and a suite of laboratories for research in areas including quantum optics, nuclear magnetic resonance (NMR) and electron spin resonance (ESR), quantum dots, superconducting qubits, coherent spintronics and quantum cryptography. The building will host IQC researchers from all three faculties (Engineering, Mathematics and Science) starting in 2011.

Courses

Students in all three faculties will be required to take two core quantum information courses (and must also meet the course requirements of their home program). These interdisciplinary courses provide a strong foundation in quantum information science. The two required core quantum information courses are:

QIC 710: Quantum Information Processing
QIC 750: Implementation of Quantum Information Processing

PhD students are also required to take two additional courses in quantum information, and fulfill a research seminar requirement, a comprehensive exam and a thesis in quantum information

In addition to the two core courses, students will be able to take a wide range of advanced courses within quantum information, offered by leading researchers in the field.

Eligible supervisors

Eligible supervisors include the core IQC faculty:

Jonathan Baugh	Andrew Childs
Richard Cleve	Joseph Emerson
Thomas Jennewein	Raymond Laflamme
Debbie Leung	Adrian Lupascu
Norbert Lütkenhaus	Hamed Majedi
Michele Mosca	Ashwin Nayak
Ben Reichardt	Kevin Resch
John Watrous	Frank Wilhelm

as well as a wide range of Associate and Affiliate Members of IQC and the University of Waterloo including:

Daniel Gottesman	Thorsten Hesjedal
Achim Kempf	David Kribs
Jan Kycia	Anthony Leggett
Robert Mann	James Martin
Roger Melko	Bill Power
Pierre-Nicholas Roy	

Inquiries may be directed to **Michele Mosca**, **Program Director**, at grad@iqc.ca.

Upcoming Quantum Information-related Conferences and Workshops

If you are reading this as a PDF, click on the links below for information on the individual conferences.

Apr 5–9: Quantum Information and Computation VIII (DS223), Orlando, USA.

Apr 12–14: Special Track on Quantum Information Computing and Communications (ITNG 2010), Las Vegas, USA.

Apr 13–15: The 5th Conference on Theory of Quantum Computation, Communication, and Cryptography, Leeds, UK.

Apr 25–28: Coherence in Superconducting Qubits, San Diego, USA.

May 16–21: Conference on Lasers and Electro-Optics and the Quantum Electronics and Laser Science Conference (CLEO/QELS), San Jose, USA.

May 23–29: Quantum 2010: Advances in Foundations of Quantum Mechanics and Quantum Information with atoms and photons (includes the Third Italian Quantum Information Science Conference), Turin, Italy.

May 24–Jun 4: Undergraduate School on Experimental Quantum Information Processing, Waterloo, Canada.

May 25–28: The Third International Workshop on Post-Quantum Cryptography (PQCrypto 2010), Darmstadt, Germany.

May 25–29: The 41st Annual Meeting of the APS Division of Atomic Molecular and Optical Physics (DAMOP/DAMPΦ 2010), Houston, USA.

May 28–Jun 1: XIII International Conference on Quantum Optics and Quantum Information, Kyiv, Ukraine.

Jun 14–17: Second Workshop on Theory and Realisation of Practical Quantum Key Distribution, Waterloo, Canada.

Jun 19–22: Quantum Channels, Quantum Information - Theory & Applications, Toruń, Poland.

Jun 21–25: Control and optimization of open quantum systems for information processing, Palo Alto, USA.

July 12-16: The Seventh Annual Canadian Quantum Information Students' Conference, Calgary, Canada.

July 17–23: 10th Canadian Summer School on Quantum Information, Vancouver, Canada.

July 18–23: Quantum Computing Special Session (WCCI 2010), Barcelona, Spain.

July 19–23: The 9th International Conference on Quantum Communication, Measurement, and Computing (QCMC 2010), Brisbane, Australia.

Information on additional conferences may be found at http://quantum.info/conf/.

APS Topical Group on Quantum Information

Changing *Times*

In deference to our colleagues south of the equator, we have decided to dispense with our alignment of the publication to northern hemispherical seasons and, instead, simply proceed "quarterly." Issues will now be published roughly at the ends of March, June, September, and December, corresponding to the four quarters of the calendar year. (It's 2010 in Australia, right?)