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# Professor Danny Segal – scientist and scholar

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Professor Danny Segal (1960-2015) was a talented scientist who worked at Imperial College London for nearly twenty five years until his untimely death in 2015. His main research interest was in the area of spectroscopy and laser cooling of trapped ions in Penning traps, but he was also active in the wider ion trap and quantum optics communities in Europe and made many contributions beyond his research activities to the Physics Department at Imperial.



Figure 1. Professor Danny Segal, 1960-2015.

## 1. Early career

Daniel Martin Segal read Physics at the University of Manchester and graduated in 1983. He then studied for his PhD in the Spectroscopy Group of the Physics Department at Imperial College London with Keith Burnett from 1984 to 1988. The topic of his PhD was "Collisional Redistribution of Light in the Hg-Kr System". He then moved to Oxford with Keith Burnett as a postdoctoral research associate. This period of Danny's life and the physics that he studied is discussed by Keith Burnett in another article in this Special Issue [1].

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## 2. Postdoctoral work at Imperial College

Danny returned to Imperial in 1991 as a postdoctoral research associate working with me on experiments with trapped ions. I had recently arrived at Imperial from the National Physical Laboratory where I had worked on the first laser cooling experiments in the UK. At Imperial I set up a small group working on the laser cooling of ions in a Penning trap. Danny was my first postdoctoral research assistant and he was appointed to work on experiments studying the dynamics of the ions in the trap.

At that time, tunable laser systems were much less advanced and much more temperamental than they are now. We were working with magnesium ions, which needed light at 280 nm for laser cooling. This required the light from a dye laser, pumped by an argon ion laser, to be frequency doubled from 560 nm. This system produced around 75 $\mu$W of light at 280 nm, which was just enough for the laser cooling experiments. However, the dye had to be changed every week or two and the laser had to be continually readjusted to keep it working properly. Nowadays of course significantly higher powers can be obtained much more reliably from solid state laser systems.

A Penning trap requires a strong magnetic field, and we used a high-field solenoid magnet to create the necessary field of around 1 tesla. With this system we were able to observe quantum jumps in single ions of magnesium [2], demonstrating the ability to load single ions into the trap, laser cool them to temperatures around 1 mK, and observe the ion fluorescence turning on and off due to the ion making quantum jumps between different electronic states.

We also developed a photon-photon correlation technique to directly observe the oscillation frequencies of ions in the trap. We used this to study the ion motion in a novel type of trap, the "combined trap", which used RF fields as well as the static fields of the Penning trap for the confinement of ions [3, 4].

In all of these studies, Danny showed his great experimental skill and insights into physics. He was passionate about his research and had a deep desire to investigate and understand the strange behaviour of the quantum world. He enjoyed working with PhD students and sharing his boundless enthusiasm for science with them. This continued throughout his career and his many former PhD students benefitted enormously from his excellent research supervision. He always had time for them when they needed help of any kind.

## 3. Advanced Fellowship award

In 1993 Danny was awarded an EPSRC Advanced Fellowship. This gave him funding to pursue his own research ideas for a period of 5 years. We continued to work together and the funding obtained by Danny for experiments in the area of quantum optics with trapped ions allowed us to expand our activities.

Around this time we obtained a pulsed dye laser on loan for a period of a few months. Danny was in his element working with this system as it was very similar to lasers that he had worked with during his PhD, though the rest of us in the group were very uneasy about working with the high-power pulses it produced. With this apparatus, we carried out pulse-probe experiments that measured directly the rotation speed of a cloud of ions in the trap [5].

One area that Danny was particularly interested in was the design and operation of novel types of ion trap. After the study of the combined trap, he designed a series of new traps used for different purposes, including an investigation of the effect of perturbations of the trapping field in traps [6] and the characterisation of a linear variant of the combined trap [7].

One other area of interest was the sympathetic cooling of ions. This process takes place when the trap contains two different species of ion, one of which is directly cooled using laser cooling. The other species is cooled through collisions with the laser-cooled ions. Danny was instrumental in carrying out one of the early demonstrations of this effect with molecular ions [8].

## 4. Academic appointments

Danny was appointed to a Lectureship at Imperial in 1998 and was subsequently promoted to Senior Lecturer (2001), Reader (2004) and Professor (2011). He enjoyed all aspects of being an academic, especially undergraduate teaching, at which he excelled.

He was a strong supporter of undergraduate laboratory training, and was particularly concerned about the fact that many students disliked laboratory work and did not learn very much because they were essentially just following a set of instructions without really engaging with the activity. He therefore helped bring in major reforms of the department's first year laboratory, with the aim of helping students to appreciate and understand the power of basic experimental techniques. He was also one of the pioneers of the department's use of seminar groups, which were introduced to replace small-group tutorials. These were designed to help build up students' professional skills and problem-solving ability.

He was an outstanding undergraduate lecturer and gave lecture courses which were universally acclaimed by the students, especially the second year Quantum Mechanics course which he taught for several years. In these courses he combined a deep physical insight with clear delivery and humour. He was awarded the College's Award for Excellence in Teaching in 2007.

In October 2009 the Quantum Optics and Laser Science research group (QOLS) started a Centre for Doctoral Training (CDT), funded by EPSRC. This Centre provides training in the area of Controlled Quantum Dynamics for around ten PhD students each year. As one of the Co-Directors, Danny took responsibility for setting up an MRes degree, which formed the first year of the four-year CDT programme. This was very successful, and the MRes year provides comprehensive training in both theoretical and experimental techniques employed in this subject area. Many research groups at Imperial and wider afield have benefitted from the excellent students graduating from the MRes programme, including the ion trap group. As a result, the field of Controlled Quantum Dynamics has been significantly strengthened in the UK. The CDT programme has since been renewed for a further five years.

## 5. Research interests

A major research achievement after his appointment to a Lectureship was the development of the "axialisation" technique, which was used to improve the cooling of the radial motion of ions in the Penning trap [9]. Compared to other types of ion trap, Penning traps have the disadvantage that the energy associated with one of the degrees of freedom of the ions, the so-called magnetron motion, is negative. This means that the motion is unstable and leads to problems with achieving strong cooling of the ions. Axialisation is a technique used in other fields that was adapted by Danny for use with laser-cooled ions. It made it possible to work with single ions in a much more robust way and we have continued to make extensive use of this technique since [10, 11].

Danny recognised that our experiments with magnesium (and by this time also beryllium) had the limitation that the simple energy level structure of these ions did not allow the flexibility needed to carry out experiments that could reveal the most interesting aspects of quantum phenomena. In particular, there was no electronic transition available in these ions for use in coherent control of the ion – a so-called "qubit transition" (a term widely used in the field of quantum information and quantum computing). In order to be able to carry out these types of experiments, it was necessary to move to a different ion with a more complex energy level structure, such as calcium. Danny realised that in a Penning trap this could only be done by using several lasers, which was not realistic for dye lasers due to their need for frequent readjustment. However, by this time developments of diode lasers meant that several such lasers could be operated simultaneously with acceptable reliability. He therefore applied for and was granted funding for a new setup to work with calcium. This resulted in the first laser cooling of an

ion with a complex energy level structure in a Penning ion trap [12]. Initially this required 8 diode lasers to be running simultaneously, though this was later reduced to 5 by the use of a high-frequency modulator. Despite the fact that diode lasers were much more reliable than dye lasers, keeping so many lasers running reliably was, and remains, a significant challenge.

Danny continued to explore new designs for ion traps, and he was able to design a novel and elegant structure with multiple trapping zones that allowed the transfer of ions between different zones in a direction perpendicular to the magnetic field of the trap [13]. This transfer of ions is usually only carried out along the magnetic field direction. The trap was constructed from standard circuit boards using simple fabrication techniques, in contrast to the more common precision engineering necessary for manufacturing a trap using metallic electrodes. He also enjoyed the challenge of designing traps for use in the superconducting magnet which we were using by this time, where the trapping region is extremely constrained and has very poor access.

In recent years the ion trap group has continued to pursue research on laser cooling of calcium ions, resulting in significant breakthroughs. These include the observation and control of small Coulomb crystals of ions in a Penning trap, which can take a variety of structures in one, two and three dimensions [14]. Using a highly-stable laser that Danny developed, we also achieved sideband cooling of a single ion in a Penning trap to the ground state of its motion for the first time [15]. This work set the scene for subsequent developments, and in the last two years the sideband cooling technique has been extended to small ion crystals in the Penning trap and has allowed coherent control of the ions to be demonstrated [16].

## 6. European collaborations

European research networks of various sorts have had a huge impact on research collaborations across the continent. In the field of quantum optics and quantum information there have been large benefits to the community from network activities. These networks always require much organisation and this is often concentrated on one individual. Danny was heavily involved in several of them and took on more than his fair share of administration and coordination as well as the associated travel (generally by train, as he rarely flew). These networks included QUBITS, QUEST, QGATES and SCALA. He displayed a particular skill at presenting the results of the research from different groups in a network with confidence and authority, even when some of the research topics were outside his own area of expertise.

Danny was strongly supportive of the European ion trap community in general and played a huge role in setting up the first European Conference on Trapped Ions (ECTI) which was held in the UK in 2010. This conference series has continued with biennial conferences since then, and ECTI will be held next in Israel in 2018.

He also developed a personal collaboration over several years with the ion trap group at GSI Darmstadt on the SPECTRAP project [17]. At one point this involved driving from London to Darmstadt with an assembled ion trap under vacuum in the boot of his car.

## 7. Pastoral support at Imperial

Many people remember Danny for his empathy and concern for others, particularly students. Early in his career he was the warden of Imperial's new postgraduate student Hall of Residence at Clayponds in Ealing. He took the opportunity to help shape the College's provision for postgraduate accommodation and made Clayponds a very successful and popular hall of residence. Within the Physics Department, he was the postgraduate advisor for several years, available to all physics postgraduate students if they needed to talk confidentially to a member of staff not involved in their research.

In 2012 he took on the role of Senior Tutor in the department. This is a highly-demanding role which carries overall responsibility for the welfare of around 800 undergraduate students. It requires a huge commitment of both time and energy, and Danny was happy to do this because he believed passionately in the need to care for our students and not just to teach them physics. As Senior Tutor he was always discreet, professional and caring, and he helped many students continue with their studies through difficult periods.

Danny was Senior Tutor at the time he became ill in September 2014, just after he had attended the third ECTI conference. Although he was not able to work in the department after that, he remained in active contact with the ion trap group for many months while he was undergoing treatment. He contributed to discussions about the research and was always keen to hear what was happening in the laboratory.

## 8. Outside academia

No-one is defined by their work activities alone and this was particularly true of Danny, who had a rich variety of outside interests and activities. He was a very strong family man and totally committed to his wife and children. Living in the beautiful town of Chipping Norton, he had a long journey to work each day (approaching 2 hours) but in typically positive style, rather than complain, he relished not only the opportunity to live in a beautiful place, but also the chance to work on the train! He had outstanding practical skills and spent many happy hours over the years renovating his house and building extensions.



Figure 2. One of Danny Segal's oil paintings.

Danny was a talented artist and his house has many of his own paintings (see Figure 2). When he built his latest extension, he included a room to use as a studio including a north-facing window for suitable light.

He also included a music room which could be used as a recording studio, because he was a keen musician. He loved The Blues in particular, forming a number of Blues Bands over the years, performing far and wide as singer and lead guitarist, including as a regular busker in Bonn Square in Oxford while he was working there. He was happy to share those talents at Imperial at

musical events in the Physics Department (see https://www.imperial.ac.uk/physics/news-and-events/concerts/ for recordings of some of his performances).

## 9. Conclusion

In all, I had the privilege of working closely with Danny for 24 years, mostly on the same projects, and nearly all our PhD students were supervised jointly. Danny was a fantastic friend and colleague and it was a privilege to work with him. I will personally miss him enormously. Three things in particular made him special as a physicist and an academic.

First, he was passionate about his science and was full of ideas for new experiments. Danny was at his happiest when he had the opportunity to work in the laboratory alongside his students, making things work and taking data. He worked incredibly hard to keep projects moving, even if this meant staying late in the lab, despite having a long commute home afterwards.

Second, Danny was an exceptional colleague. He was the sort of person who would always say yes if he possibly could, when he was asked for help. Danny also recognised that universities are not just about research. As a teacher he was the envy of many colleagues, including me. He had an ability to inspire students in an apparently effortless manner and he used skill and humour to convey complex ideas.

Finally, Danny was one of the kindest and wisest people I have known. He would always see the best in others and would give them the benefit of the doubt despite any evidence to the contrary. I hardly ever saw him really angry with anyone. Danny had more patience than most of us, and that came out in all his dealings with other people. Danny was a great friend and colleague, full of enthusiasm, compassion and scientific insight.

At Imperial College we celebrated Danny's life in March 2016 with an event including talks and music. A highlight of the day was hearing a poem written by Danny's daughter Rose:

### Quantum Leap

I see you, Professor of Quantum Optics
in a windowless basement lab
stalking between photomultipliers

setting traps to separate
photons from atoms from the unknown
watching them blink on the screen and fade

determining, splitting beams, watching,
measuring phase and wave for days,
asking, asking – particles or waves?

But sometimes, when you least expect
when walking the dog or washing up
you catch sight of sunlight streaming through dust
or playing in splashes between dishes

then, hands full of
starlight

frowning in the
moonglow

holding up shards of
sunlight

and fragments of the
rainbow,

you wonder, what was that question?

why did you ever need to know?
*Rose Segal*

A recording of the talks can be found at

http://wwwf.imperial.ac.uk/imedia/content/view/5423/danny-segal–a-celebration

and the musical items are available at

http://www3.imperial.ac.uk/newsandeventspggrp/imperialcollege/naturalsciences/physics/newssummary/news_26-5-2016-11-39-18.

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