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Elected FRS 1992

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Dan Walls, a pioneer of quantum optics and especially the study of non-classical light, died in Auckland on 12 May 1999 after a battle with cancer, at the age of 57 years. Dan Walls completed a PhD with Roy Glauber at Harvard in 1969 and joined the University of Waikato in 1972. Together with his colleague Crispin Gardiner, during the next 25 years he established a major research centre for theoretical quantum optics in New Zealand and built active and productive collaborations with groups throughout the world.

EARLY HISTORY AND FAMILY

Dan Walls was born in Napier, in Hawkes Bay in New Zealand, on 13 September 1942, the son of James Reginald Walls and Barbara Gertrude Walls (née Leddra). He had one sister. He married Fari Khoy in 1968 and they had one son, Mark, born in 1980. This marriage ended in 1986. His partner in later years was Pamela King.

Dan was an enthusiastic sportsman as a young man and played at half-back in rugby, even while a PhD student at Harvard. John Tucker, Dan’s co-author on his first paper, has written to one of us (G.J.M.):

The best thing about Danny was his fanatic enthusiasm for work and life in general. My most vivid memories of him are the Saturday nights when he would come back to the dorm from rugby matches with broken teeth and bloody contusions, pick up a beer and declare it was just great, really great mate!

He became a fiercely competitive tennis player in his later years, challenging many at scientific meetings.
Biographical Memoirs

EDUCATION

He attended Auckland Grammar School (vying for top honours with his fellow-pupil and long-time colleague Crispin Gardiner (now a professor at Victoria University, Wellington). He became enrolled at the University of Auckland in 1961, gaining a BSc in physics and mathematics and a first-class honours MSc in physics.

Walls then went to Harvard as a Fulbright Scholar, working for his PhD under the supervision of Roy Glauber (ForMemRS 1997; 2005 Nobel laureate in physics), and obtained his doctorate in 1969. His thesis was entitled ‘Topics in nonlinear quantum optics’.

EARLY CAREER

After his postgraduate work in Harvard, Walls went on to do postdoctoral research in Auckland (1971) and in Stuttgart with Hermann Haken. He was appointed a senior lecturer in physics at Waikato University in 1972, where he became a reader in 1976 and a full professor in 1980. He quickly established Waikato as a major centre for theoretical quantum optics, supervising several postgraduate students, attracting other staff members to his field, and establishing what became a major series of international conferences in quantum optics. His series of conferences really accelerated the development of quantum optics in Australasia, and each had an attendance drawn from the leaders of the field worldwide. Given what he perceived as the relative isolation of New Zealand physics at that time, Walls pursued an active strategy of collaborating with the leading quantum optics groups around the world, with a punishing regular travel schedule of flights with very many stopovers to engage with colleagues: his massively thick airline tickets became legendary in the field. He stimulated many of the leading researchers in his field (and stimulated young researchers who went on to leadership in later life) to undertake new research projects through his enthusiastic and vigorous approach to the scientific life.

Dan’s first PhD student was Ken McNeil. Howard Carmichael first undertook an MSc with Dan while he was still in Auckland, and then moved to Waikato in 1972 to do a PhD. Given Dan’s lifetime focus on quantum science, it is interesting to recall that he had a PhD student at Waikato by the name of Lindsey Planck, who worked in the biophysics area. Also in the group at that time was Peter Drummond, who subsequently became a leader in theoretical quantum optics. One of us (G.J.M.) was also a student of Dan Walls in Waikato, who remembers with great fondness the stimulating atmosphere in the group at that time, led by Dan and by Crispin Gardiner, his very long-time associate.

RESEARCH CONTRIBUTIONS

Quantum optics is the application of quantum electrodynamics to low-energy interactions of light and matter. In the late 1960s Glauber, at Harvard University, initiated the study of optical coherence of the quantized electromagnetic field. He determined the quantum states of the field corresponding to well-understood coherence properties as demonstrated in optical interferometry, thus providing a quantum explanation for the wave properties of light. In a complementary fashion the quantum theory of photon detection was developed by Glauber
Daniel Frank Walls (1963), and independently by Len Mandel and Emil Wolf (Mandel 1963) at the University of Rochester. The Glauber–Mandel–Wolf formula for photon detection probabilities is a conditional Poisson process, conditioned on the quantum state of the field. Through these early studies of Glauber, Mandel and Wolf, the field of quantum optics can be said to have had its beginning, along with the famous Hanbury Brown–Twiss experiment (Hanbury Brown & Twiss 1956) in Manchester, which began the whole subject of photon correlations. While confirming that certain field states would reproduce well-known results from classical physical optics, the new field of quantum optics indicated that uniquely quantum behaviour would become evident for appropriate sources and certain kinds of measurement scenarios. Through the close interaction of theoreticians and experimentalists, the history of the subject for the next three decades can be seen as a steady realization of these properties.

The 1970s could be regarded as the decade of quantum features of photon counting statistics, culminating in the prediction and observation of photon antibunching, in which Walls and Carmichael made pioneering contributions (3)*. In the 1980s Walls’s focus returned to the complementary ‘wave’ aspect of light as attention focused on phase-dependent properties such as squeezing, after a profitable early interaction with Carlton Caves at California Institute of Technology (Caltech). Milburn and Walls published the first exact calculation of squeezing in second-harmonic generation (5). Both photon antibunching and squeezing in some ways appear as quantum restrictions on semiclassical effects. In the 1990s the truly non-classical aspects of entanglement became the major area of investigation after pioneering work on Bell’s inequalities by Clauser et al. (1969), Aspect et al. (1982) and others over the preceding decades. Margaret Reid’s thesis supervised by Walls, on Einstein–Podolsky–Rosen (EPR) correlations of light fields, initiated in a sense the current research field of continuous variable quantum information. In every aspect Dan Walls proved to be a major innovator and a driving force for the unfolding experimental progress.

Dan Walls’s first paper in quantum optics, co-authored with John Tucker (now at University of Illinois – Urbana Champaign) originated as a term paper set by Glauber as part of his quantum optics course at Harvard. Dan and John entered Harvard together and became fast friends. Another of Glauber’s students, Ben Mollow, had just published an analysis of quantum statistics in a model parametric amplifier (Mollow 1967). Instead of summarizing previous work, Dan and John independently decided to repeat this same analysis for a model frequency converter. They were both surprised when Glauber called them in and told them they had produced almost identical calculations. He then suggested that they submit them for publication (1). In the following term, Dan and John took Nicolaas Bloembergen’s class in nonlinear optics (Bloembergen was subsequently awarded the 1981 Nobel Prize in Physics) and extended this work to a travelling-wave model for their joint term paper (2).

Dan’s early research focused on open quantum systems using master equation techniques. Earlier work in quantum optics had been concerned with the simpler cases of conservative systems consisting of one or few modes without too much attention being paid to the dissipative effects of the external environment and consequent fluctuations and noise. Quantum optics provided a clear context in which to investigate quantum effects in such open systems, with the added advantage that prediction stood a good chance of experimental verification. As mentioned briefly above, Howard Carmichael, Dan’s second PhD student,
started working on master equations as part of his MSc research. They decided to investigate resonance fluorescence, the light emitted by atoms driven by external radiation fields, because this seemed like a good application of their master equations to two coupled open quantum systems. This work coincided with the considerable interest among the fledgling quantum optics community, both experimental and theoretical in resonance fluorescence. This research initiative led quickly to the prediction of one of the truly quantum features in optics: photon antibunching.

In 1969 Mollow had published the spectrum of the scattered light in resonance fluorescence (Mollow 1969). Quite definite predictions were made regarding the separation, widths and relative heights of the three peaks in the fluorescent spectrum when an atom was driven non-perturbatively. There was some debate at the time over these particular predictions with various alternative derivations in circulation. Using their newly developed master equation techniques, Walls and Carmichael derived the form of the spectrum in 1976 that agreed with experimental results obtained in Rochester by the group of Carlos Stroud. Their theoretical work was published as a paper in *Journal of Physics B* (4) and was well received. In a letter to Walls, Stroud said:

Thanks for the continuing stream of reprints. The latest batch, which included your J. Phys. B paper, prompted me to write and thank you for writing what may be the most clearly written paper in the long history of the resonant Stark effect.

Dan and Howard then went on to calculate the second-order correlation function to explore the statistics of resonance fluorescence. Walls’s interest in this quantity was sparked when he attended a quantum electronics conference in Oxford in 1975. In a letter to Carmichael (dated 3 September 1975), he reported that some people presented results in agreement with their results on the resonance fluorescence spectrum but added: ‘our paper upstaged them with the work on the second order correlation function’. In the same letter Walls went on to describe how antibunching would constitute an interesting test of the quantum character of the light emitted in resonance fluorescence.

In fact Howard and Dan were well aware from their earlier work on resonance fluorescence that the second-order correlation function showed a zero at zero delay; that is, photon antibunching. They were able to easily explain it in terms of the emission statistics that one would expect from a discrete level structure. In the original handwritten MS is the following sentence:

It is interesting to note that this correlation function vanishes for $\tau = 0$. This corresponds to the necessary temporal separation of photons arising from a process in which an absorption follows every emission.

As ever, Walls was well tuned into the possible experimental implications for his theoretical work. In the final version of the paper, Carmichael and Walls added: ‘This effect arises solely in a QED treatment and if observed would provide a test of QED versus the semiclassical theories.’

Squeezed optical states, a major part of Walls’s subsequent interest that occupied him throughout the 1980s, illustrate the Heisenberg uncertainty principle for the amplitudes of the electromagnetic field. Quantum electrodynamics indicates that independent field modes can be regarded as quantized simple harmonic oscillators. The canonically conjugate variables, the analogue of position and momentum for mechanical oscillators, are the in-phase and quadrature phase amplitudes of the cosine and sine components of the field. In QED these
are represented by non-commuting operators and thus field states must satisfy an uncertainty principle for these quantities. If the uncertainty in one of the quadrature phase amplitudes for the field were reduced below that for the vacuum state of the field, the uncertainty of the quadrature amplitude would be increased inversely.

Squeezed states were introduced into quantum optics by Horace Yuen, under the name two-photon coherent states (Yuen 1976). Caves (1981) coined the name ‘squeezed states’, and that name graphically captures how the noise in one quadrature may be squeezed below the vacuum noise as the canonically conjugate quadrature noise bulges out. Caves also showed how such states might be used to improve the displacement sensitivity of optical interferometers, with principal application to the problem of detecting weak gravitational radiation. This latter application developed from the concept of quantum non-demolition quantum measurements first introduced by Vladimir Braginsky (Braginsky et al. 1980) and explored in great detail by Kip Thorne and Carlton Caves (Caves et al. 1980) as a vehicle to aid in the detection of gravity waves.

In 1980 one of us (G.J.M.) started a PhD research project with Walls. During a visit to the USA in early 1980 Walls met Caves, then at Caltech, and was introduced to the notion of squeezed states of light. Immediately upon his return, he and his PhD students began an investigation of how such states might be produced in the laboratory. It was known that parametric amplification was a likely phenomenon to illustrate optical squeezing, because the phase-dependent nature of the amplification would simultaneously amplify one of the field amplitudes while de-amplifying the quadrature phase amplitude. Dan Walls thus returned to his first research topic as a student in quantum optics. Armed with the tools of master equations and corresponding Fokker–Planck formalism for the fluctuations that he and his group had developed, it was possible to include the much more realistic case of parametric amplification inside a damped optical cavity: an optical parametric oscillator.

In 1979 Dan together with Peter Drummond, then a PhD student, had found an exact quantum steady state for the parametric oscillator. G.J.M. was given the task of using this solution to calculate the degree of noise reduction in the field amplitudes. The parametric oscillator has a steady-state bifurcation as the driving field is increased. Below threshold the average field amplitude is zero. At a critical value of the driving field, however, the state becomes double peaked on two nonzero field amplitudes 180° out of phase. The intensity of the field at this threshold begins to increase with increasing driving field. It was immediately found that the intracavity field amplitude, in phase with the driving field, would show noise reduced below the vacuum level, with increasing noise in the quadrature amplitude. However, the noise reduction was limited to a factor of 50% at threshold, after which it would steadily return to the vacuum level, and beyond as the driving field was increased.

Walls moved to a chair at the University of Auckland in 1987, and once again established an international centre in quantum optics. His colleagues and students there included John Harvey, Matthew Collett, Sze Tan, Murray Holland and Kurt Jacobs. We mentioned above his founding of the important series of international conferences in Waikato. After his move to Auckland, this meeting series continued with great success in Rotorua. In the 1990s his research interests turned to laser-cooled atoms and ions, in which he pioneered studies of atom optics and Bose–Einstein condensation. Once again he was attracted to these areas by the then recent availability of experimental tests. Notable at this time was his work on the role of measurement in spontaneous symmetry breaking and the generation of a proper understanding of the phase of a Bose condensate.
Dan Walls was elected to the Fellowship of the Royal Society in 1992, one of only 37 New Zealand-born scientists up to that time to be so elected in the history of the Society. He was in addition a Fellow of the American Physical Society and of the Royal Society of New Zealand. He was awarded many medals and prizes, including those from the College of France and the University of Helsinki. In 1986 he was awarded the Michaelis Medal by the University of Otago, and in 1988 the Hector Medal by the Royal Society of New Zealand. He received the prestigious Einstein Prize for Laser Science in 1990 from the USA and in 1995 the award of the Paul Dirac Medal for Theoretical Physics by the Institute of Physics, UK. In 1999 he was awarded the Australian Optical Society Medal. His monograph entitled *Quantum optics* (6), co-authored with one of us (G.J.M.) and published by Springer, remains in print and is in its second edition.

Dan Walls suffered from health problems in later life, culminating in the cancer from which he died at the very early age of 57 years, still very much a leader and innovator in the field that he had done so much to foster.

**APPOINTMENTS AND HONOURS**

*Appointments*

1972–76 Senior lecturer in physics, University of Waikato
1976–79 Reader in physics, University of Waikato
1980–87 Professor of physics, University of Waikato
1987–99 Professor of physics, University of Auckland

*Membership of professional societies*

1981 Fellow of the American Physical Society
1986 Fellow of the Optical Society of America
1989 Fellow of the New Zealand Institute of Physics
1992 Fellow of the Royal Society

*Visiting positions*

1972 Visiting scientist, Royal Radar Establishment, Malvern (with Dr R. Pike)
1975 Visiting scientist, Technical University of Munich (with Professor W. Kaiser)
1976 Visiting scientist, Université Libre de Bruxelles (with Professor I. Prigogine)
1977–78 Visiting professor, University of Munich (with Professor H. Walther)
1980 Visiting fellow, Joint Institute for Laboratory Astrophysics
1981 Visiting professor, Max Planck Institute for Quantum Optics in Munich
1982 Visiting professor, Max Planck Institute for Quantum Optics in Munich
1983 Visiting professor, Max Planck Institute for Quantum Optics in Munich
1984 Visiting professor, Institute for Theoretical Physics, Santa Barbara
1986 Adjunct professor, University of Arizona
1987 Visiting scientist, IBM Research Laboratories, San Jose
Daniel Frank Walls

1988 Adjunct professor, University of Arizona
1989 Adjunct professor, University of Arizona
Visiting professor, Max Planck Institute for Quantum Optics in Munich
Visiting scientist, IBM Research Laboratories, San Jose

Postdoctoral positions
1969–70 University of Stuttgart (with Professor H. Haken)
1970–71 University of Auckland, New Zealand

Scholarships, fellowships and prizes
1959 National Scholarship (New Zealand)
1960 Junior Scholarship (New Zealand)
1965 Annual Prize in Physics (University of Auckland)
1966–69 Frank Knox Memorial Fellowship (Harvard University) Fulbright Fellowship
1970 Cheeseman Pond Memorial Prize (Auckland Institute and Museum)
1978 Medal of the College of France
1980 Visiting Fellowship at the Joint Institute for Laboratory Astrophysics, University of Colorado, and the National Bureau of Standards
1981 Medal of the University of Helsinki
1984 Claude McCarthy Fellowship
1986 Adjunct professor, University of Arizona
1988 Hectors Award, University of Otago
1988 Hector Medal of the Royal Society of New Zealand
1990 Einstein Prize for Laser Science

Professional activities
Member of the IUPAP Commission on Quantum Electronics, 1982–84
Vice President of the New Zealand Institute of Physics, 1982–83
Member of the International Council on Quantum Electronics, 1989–
President of the New Zealand Institute of Physics, 1990–92

Acknowledgements
In the preparation of this memoir we have benefited from contributions from many of Dan Walls’s friends and colleagues. In particular we thank Crispin Gardiner, John Tucker, John Harvey, Howard Carmichael and Carlos Stroud Jr.

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Biographical Memoirs


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The following publications are those referred to directly in the text. A full bibliography is available as electronic supplementary material at http://dx.doi.org/10.1098/rsbm.2014.0019 or via http://rsbm.royalsocietypublishing.org.