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Ion beams and channelling: the early days with Jak Kelly

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Abstract

This paper contains some personal perspectives of the lessons learnt during my PhD studies with Jak Kelly at UNSW. Jak was passionate about science, had boundless enthusiasm, was an eternal optimist, was an 'ideas' person and innovator, as well as a superb motivator for his students and co-workers. I owe him much for his impact on my career in science.

Introduction

I first encountered Jak Kelly as an undergraduate student at UNSW in the mid-1960s. He was clearly the most enthusiastic and passionate lecturer in my early undergraduate years. His lecturing style was decidedly theatrical and compelling. It was not a surprise to me that his daughter Karina showed much of that style in her media successes years later. During my Physics Honours year I was called up for national service. I sought Jak out for advice on whether a PhD might be a viable choice to keep me out of the army! Jak and Brian Lawn, another impressive academic member of staff at that time, suggested an intriguing topic for a PhD that brought together their individual research interests: ion channelling in Jak's case and brittle fracture in Brian's case. Jak explained that the phenomenon of ion channelling had only been discovered a few years earlier and the field was ripe for the picking. I was impressed and signed up for a PhD. The topic turned out to be a bizarre and, ultimately, an incompatible union of research directions, but more about that later.

There were four attributes of Jak that stood out during my PhD time: i) he was a fantastic 'ideas' person but I learnt early that some filtering was necessary to give a reality check and pick those directions that were feasible given our meagre resources at UNSW; ii) he was an eternal optimist and always saw opportunity in adversity; iii) he was a fabulous motivator and his boundless enthusiasm helped me face the most daunting of problems with confidence; and iv) he was a superb innovator and taught me to improvise with what was available to achieve an important research goal. I have chosen three examples or stories from my PhD time that illustrate these attributes.

The 1.2 MV Cockcroft-Walton accelerator

Part of Jak's motivation for suggesting my thesis topic, built around ion channelling, was that he was in the process (in early 1969) of negotiating the purchase of the ANU Cockcroft-Walton accelerator. As a typically naïve student, I believed Jak when he said that the accelerator should be fully running within about 6 months and I could plan to do my channelling measurements across fracture interfaces in silicon on that machine. Little did I know at that time that a suitable home for this machine had not been found, and that was only the start of the problems that needed to be solved before the machine was usable! In truth even Jak didn't realise the enormity of the task. Anyone that has worked with accelerators will know that, when they are left idle, (essential) bits are progressively cannibalised. It was no different with the ANU machine that was decommissioned in 1967. Jak managed to convince the University to buy an old tram maintenance shed opposite Randwick racecourse. It was an ideal location, with very solid walls and a ceiling high enough to house the very impressive Cockcroft-Walton accelerator shown in its glory days at ANU in Fig.1. The charging system and the three stack configuration of the machine created a sight to behold.

When the accelerator arrived at UNSW there were many parts missing and the electrical wiring, vacuum system, beam lines and data collection needed to be completely rebuilt. Undaunted, Jak set about mobilising a team to work on it. Bob Dalgleish, a very talented PhD student who had a strong electronics background from an earlier life, played a major role in finally getting it operational by the end of 1972. Alas, too late for my own PhD! Nevertheless, the accelerator was a major focus of Jak's group activity at the time and its successful installation was a huge achievement, a testimony to improvisation that brought great credit to Jak and those who worked on it.

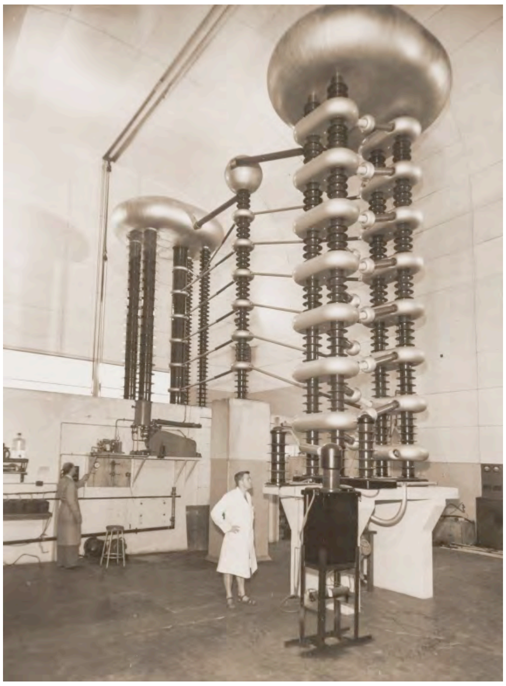

Figure 1: The 1.2 MV Cockcroft-Walton accelerator as installed at the ANU in the early 1950s. The high voltage generator stack is at the right. A uniform voltage gradient is applied to the acceleration tube via the central condenser stack. The ion source is located in the left side 'bun' at the top of the acceleration column.

I can well remember the occasion of the first time voltage was obtained on the ion source 'bun'. We were all awestruck! Jak had to demonstrate that high voltage was 'safe' if there was no path to ground. He proceeded to climb into the 'bun', the ladder was removed and he asked Bob to wind up the voltage. I believe we reached 50,000 volts with Jak up there, his head and shoulders visible above the bun. Jak's hair was extended in all directions, like Einstein, and one of my co-students called out: 'Jesus Christ', and at that moment, to all of us, Jak was!!

Ion channelling at AAEC: the early days

Although the Cockcroft-Walton was not operational in time, not all was lost for my thesis. Jak had already established a successful collaboration with Roger Bird at the Australian Atomic Energy Commission (AAEC) at Lucas Heights and a 'channelling' beam line had been constructed by PhD student Murray Hollis. When I started Murray had not obtained any channelling data but with the help of Pat Price, a PhD student who followed on from Murray, he managed to achieve channelling in gold foils and completed his thesis by early 1969. To achieve channelling Murray needed to construct a goniometer[1] in a vacuum chamber that had 5 degrees of freedom, all controlled from outside the vacuum. It was a beast of a system and held together just long enough for Murray to complete!

Pat and I were forced to build another scattering chamber and goniometer to have any hope of further channelling experiments. I remember talking to Jak at the time and asking him how we could get a system up and running in a reasonable time. I had been doing X-ray experiments on fractures in silicon using a simple goniometer in air and wondered how this would go in vacuum with flexible angle and translation control through vacuum feedthroughs. Jak's immediate response was: 'try it and I think I have just the chamber for it'. I dusted off an ancient chamber that Jak had used years earlier at Sydney University and within two weeks we had a very inelegant looking, but workable, goniometer in a vacuum chamber that could hold a reasonable vacuum despite the lubricants on the goniometer drives. It was connected to the channelling line at AAEC and we were off and running. This was symptomatic of the type of improvisation that Jak encouraged in the group. It is a skill that has held me in good stead over my career in science.

The experiments that Pat and I did at Lucas Heights were the first Rutherford backscattering and channelling measurements in Australia. They led to papers on radiation damage build up in alkali halides (Price et al., 1973) and radiation effects in quartz (Williams and Lawn, 1973). The chamber, beam line and analysis system at AAEC remained in use until the early 1980s, servicing many other students and researchers, until it was replaced by a more user-friendly commercial system.

As an aside, Murray Hollis went off to Chalk River laboratories in Canada and returned to the ANU, and became the laboratory manager of the Research School of Physical Sciences, the very School of which I became Director a couple of years after Murray retired. Pat Price came from a sugar cane farm in North Queensland to do his PhD with Jak. He also went off to Canada on a post-doctoral fellowship, before returning to Australia as an engineer in industry.

Channelling without an accelerator: the pinhole camera

I realised about 6 months into my PhD that I was very unlikely to be able to achieve my original goal of ion channelling across a fracture interface to dynamically measure crack tip separation. I can remember the first time I went to talk to Jak about this problem I was quite depressed. I also

[1] An instrument used for the precise angular orientation of faces of a crystal with respect to some reference direction; e.g., the incoming ion beam direction.

remember coming out of that meeting totally energised and enthusiastic again. So, what did Jak say? I honestly can't remember but there was certainly no ready solution to my dilemma. That was the effect Jak had on his students: he could motivate and encourage them simply by his positive attitude and passion. What I do remember is that he gave me a paper by a French group, Yves Quere and co-workers, and said I should read it as it may lead to something useful for my project.

The said paper was in French (Quere, 1968) and described how a radioactive source (^{241}Am, which produced 5.46 MeV α–particles) could be used to obtain channelling patterns by inserting thin samples between it and a track-recording cellulose film. I discussed this paper with another of Jak's PhD students, Hans Nip, and the two of us decided to try a twist on the French method. We built a pinhole camera that is shown in Fig. 2. We figured that it could be used for observing channelling phenomena. We actually built the camera and obtained channelling patterns before we told Jak anything about it. When he saw the results he was delighted and told us that this was just the sort of innovation he wanted to see from his students. The trick with these experiments was to polish the single crystal sample to a precise thickness that was too thick for α–particles that entered the crystal in a random direction to penetrate through it but thin enough for easy penetration of well-channelled particles. The distances between sample and source (d_s) and sample and film (d_f) could be varied in our vacuum camera as well as the penetration angle (by viewing different distances from the film centre). A magnification can be defined as d_f/R_f and adjusting the various spacings allows a range of channelling phenomena (and defects which inhibit channelling) to be observed. Fig. 3 shows channelling transmission patterns for 3 different oriented single crystal silicon samples. The width of the bright lines allows the channelling critical angles to be measured. At the time, these patterns had only previously been obtained by expensive high energy particle accelerators.

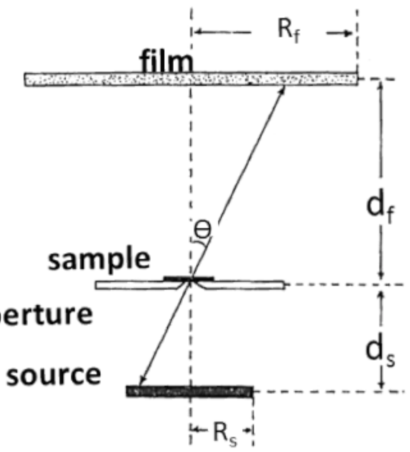

Figure 2: A schematic of the vacuum pinhole camera arrangement whereby α–particles passed through an aperture and sample and impinged onto a cellulose nitrate film. Etching the film revealed the individual α–particle tracks and the channelling directions in the crystal. From Nip and Williams (1972).

Both a conference presentation and a journal paper (Nip and Williams, 1972) were obtained from this work. I presented the paper at a conference in Oslo in 1971 which was very well received. In fact, I was congratulated on the innovative method and had three post-doctoral offers, one of which I accepted at the University of Salford in the UK working with George Carter. Again, this type of innovation was strongly encouraged by Jak: I owe him much for the training in his group that set up my future career in science.

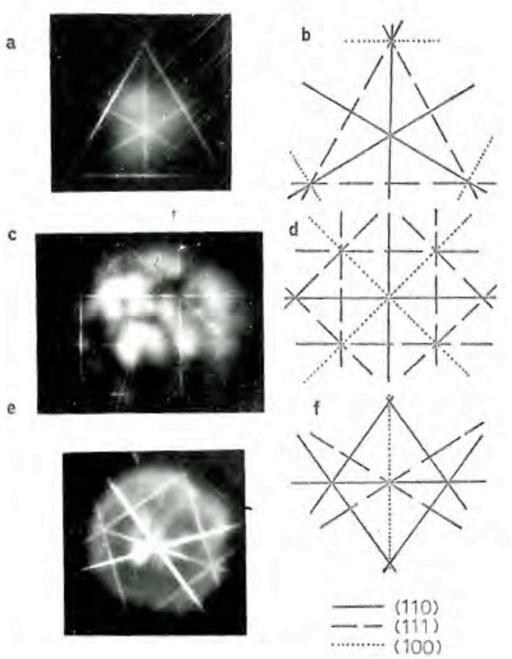

Figure 3: Pinhole channelling patterns from a) <111>, b) <100> and c) <110> oriented silicon thin samples, with the respective stereographic projections in d), e) and f). From Williams (1972).

Very sadly, Hans Nip committed suicide around the time I presented the Norway paper. It was not known by any of our rather close group that Hans was struggling with 'demons' that he could ultimately not overcome. Outwardly he appeared a happy go lucky person, who liked to share jokes and perspectives on life, including his very insightful poems of the week, with his friends and colleagues. Jak was strongly affected by this sad event, chastising himself that he did not detect a problem within such an otherwise caring group of people. For my part, I have become very friendly with Hans's sister Renee and family in the Netherlands. A few years ago she visited Australia and Sydney to see for herself what Hans had described to her as a great country.

Perspectives

Towards the end of my PhD I was married to my wife Ros of over 40 years now. Jak and Irene were at the wedding, as were many of my UNSW colleagues. At events such as this Jak would be excellent value, with an endless number of very witty stories and anecdotes. Years later during my post-doctoral fellowship at the University of Salford in the UK, the Kelly family visited us. They crammed into our very small flat and I can remember that Karina (at about age 14) babysat our two small children while we went out for a meal.

If I look back at where my career has gone, I have a lot to thank Jak for. In my early days in the UK and Denmark, I quickly realised that improvisation and adaptability, the ability to think laterally and problem solving, attributes that I had learnt from Jak, were highly valued by my new colleagues. I was given a problem when I arrived in Salford to measure the range distributions of various ions in materials. I realised that the depth resolution of the Rutherford backscattering method I was using was barely sufficient. It needed to be improved but what to do? After a little thought about how the resolution was improved in the channelling pinhole camera I decided to dramatically change the entrance and exit angle of the analysis beam, calculating a large enhancement in effective depth resolution. It worked better than I imagined. In fact, this simple twist to the Rutherford backscattering technique to improve its depth resolution, a small step learnt quite naturally in working with Jak, helped establish my scientific credibility. It led to collaborative and job opportunities and a very enjoyable life in science. I thank you Jak for giving me the chance to work with you, for what you taught me that not only enriched my career but engendered in me a passion and enthusiasm for science that I have endeavoured to pass on to others.

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Professor Williams obtained his BSc (1969) and PhD (1973) degrees from the University of New South Wales before moving to Europe and North America for a series of research and industry appointments, including a member of technical staff at Bell Telephone Laboratories, New Jersey, USA. He returned to Australia to take up an academic post at the Royal Melbourne Institute of Technology in 1978 and became Director of the Microelectronics and Materials Technology Centre in 1982. In 1988 he moved to the Research School of Physical Sciences at ANU as Foundation Professor of the Department of Electronic Materials Engineering. Both of these R&D efforts involved leading large research teams focussed on innovative materials and devices research covering aspects of both fundamental interest and applicability to industry. In 1997 he assumed the additional role of Associate Director of the Research School of Physical Sciences & Engineering at ANU and took up the Directorship of the School in 2002. In 2012 he retired and is now an Emeritus Professor of Electronic Materials Engineering at the ANU.

Professor Williams has carried out research in diverse areas of materials science, nanotechnology, ion-solid interactions and semiconductors for over 40 years. He has published over 450 refereed papers and five books in a broad spectrum of sub-fields within semiconductors, materials science and processing, device fabrication and engineering. His papers are well cited with an h-index of 50 and over 8,000 citations in total. He is particularly well known internationally for his pioneering work on ion implantation into semiconductors, solid phase epitaxial growth of silicon, innovative development of ion beam analysis methods, impurity gettering in silicon and nanoindentation of semiconductors, the latter area leading to prospects for novel patterning of silicon at room temperature. Over the past 20 years he has had an average of 5 invitations per year to deliver keynote plenary or invited papers at major international conferences. He has served on the editorial board of ten international journals and three international conference series. He was awarded the Boas Medal of the Australian Institute of Physics in 1993 and the Thomas Rankin Lyle Medal of the Australian Academy of Science in 2011. He is a Fellow of the Australian Academy of Science, the Australian Academy of Technological Sciences and Engineering, the Materials Research Society, American Physical Society, is President of the Australian Materials Research Society and is an IEEE distinguished lecturer. He has served on the MRS Council and has been a Vice President of the International Union of Materials Research Societies. He has been the founding director or initiator of two spin off companies, Acton Semiconductors and WRiota, in 1999 and 2004, respectively.