Frank Nabarro: A journey through science and society

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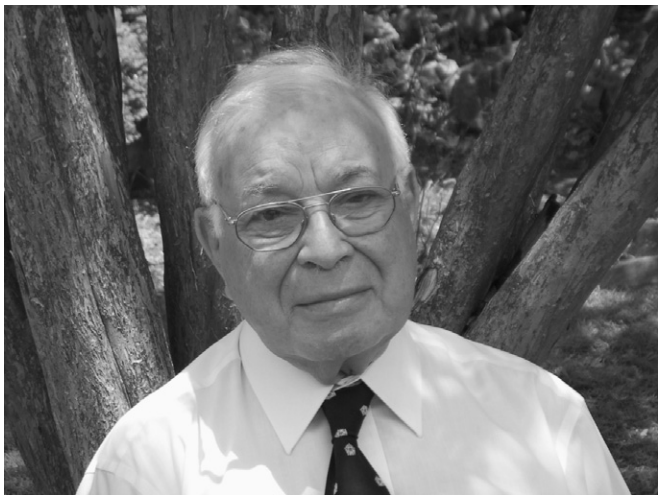
IN A CAREER SPANNING ALMOST SEVENTY YEARS, FRANK NABARRO ACHIEVED WORLD RENOWN for his pioneering contributions to the theory of crystal lattice dislocations and their role in the plastic deformation of solids. He wielded enormous influence on materials science through his acclaimed monograph, *Theory of Crystal Dislocations,* the encyclopaedic series of books, *Dislocations in Solids,* which he edited, and innumerable personal ties. In the various offices he held at the University of the Witwatersrand in Johannesburg, and through his membership of numerous scientific societies and committees, he played an important role in the development of science in South Africa and the transformation of our society. Nabarro possessed to a remarkable degree the ability to bridge cultures, whether scientific, political or social, and was sought out by many for his knowledge and wise counsel. He questioned preconceived notions and prevailing wisdom, and, through his personal attributes and extraordinary achievements, acquired legendary status in his lifetime.



Frank Reginald Nunes Nabarro was born on 7 March 1916 in London, England. He received his schooling in Nottingham and, in 1934, went up to New College, Oxford, to read physics. Once there, as he put it, 'T.C. Keeley, who was in charge of the practical classes, soon realized that my strength lay on the theoretical side', and he proceeded to take first class honours in mathematics and physics.

There was a setback in his first venture into research, when after several months of work on the theory of magnetic coercivity, he discovered that the problem had already been solved by Becker in Germany, but he was undeterred. Guided by the future Nobel laureate Nevill Mott, in 1940 he published the first quantitative estimate of the flow stress of a crystal hardened by a solid solution or coherent precipitate, pointing out the importance of the flexibility and the tension of dislocations in determining the flow stress. This was a field in its infancy, since it was only in 1934 that the essential role of dislocations in plasticity had been recognized by G.I. Taylor, E. Orowan and M. Polanyi. In their 1936 book, *Theory and Properties of Metals and Alloys,* Mott and Jones state, 'We make no mention of the strength of alloys, which is of the greatest technical importance, because it has not yet proved possible to apply the methods of atomic physics to the problem.' Nabarro's attraction to quantum mechanics at that time (what bright young theoretical physicist is unmoved by its siren call?) found expression in a paper with Herbert Fröhlich on the orientation of nuclear spins in metals. Two of his four early papers were communicated to the Royal Society, an exceptional achievement for someone of his age.

During the war years, Nabarro worked for the British Army Operational Research Group (AORG), an amazing gathering of talented individuals who included Maurice Wilkes, Patrick Blackett, Andrew Huxley and Nevill Mott. The head of AORG was Brigadier Basil Schonland, who was later to become the first president of the South African Council for Scientific and Industrial Research (CSIR) and to play an important role in the recruitment of Nabarro to the University of the Witwatersrand (Wits). Nabarro reminisces how in AORG he 'helped Mott on problems of diffraction affecting the accuracy of anti-aircraft radar, studied the effectiveness of anti-aircraft shells and worked out the consequences of Solly Zuckerman's experiments on the penetration of shell fragments into telephone directories and legs of beef.' For his services, Nabarro was awarded the MBE* in 1946.

With the cessation of hostilities in 1945, Nabarro was awarded a Royal Society Warren Research Fellowship and resumed his academic career in Mott's group at Bristol University. This was a particularly exciting time at Bristol, that saw a large influx of talented young people from the liberated territories and elsewhere. This included two South Africans, Jan van der Merwe, who wrote the seminal papers on the role of misfit dislocations in epitaxy, and somewhat later, Alan Stroh, who died tragically at a young age, but not before making revolutionary contributions to the mathematical theory of anisotropic elasticity. There was a second legendary group at Bristol at the time, that of Cecil Powell, who was to win the Nobel prize for fundamental discoveries in cosmic ray physics. Nabarro writes of this period: 'The problems that Mott's group was tackling were less fundamental than those posed by cosmic rays, but we felt that we were doing just as good physics. We were breaking new ground, and the fact that our work might be of value to industry gave it weight in another dimension which could compensate for its lack of 'fundamentality'.' The progress of physics takes strange turns, and it may be, as suggested by Frank Wilcek, that topological ideas used in describing dislocations and other defects in solids will be needed for the understanding of the cosmic medium.'

During his Bristol period, Nabarro was responsible for advances in the theory of metal plasticity and work hardening, describing the atomic structure of crystal dislocations, studying the interaction between sound waves and dislocations and inventing the concept of diffusional

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The Bristol Physics Department after the war. Nevill Mott and Cecil Powell to right of centre front. Nabarro at back on right, Jan van der Merwe second row, second from left.

creep. He enjoyed relating how, in treating the phenomenon of dislocation pile up, he was confronted by a particularly difficult mathematical problem. He took it to H.H. Heilbronn, who solved it in short order, but refused to have his name attached to the resulting paper [Eshelby J.D., Frank F.C. and Nabarro F.R.N. (1951). The equilibrium of linear arrays of dislocations. *Phil. Mag.* **42**, 351–364], 'for fear of having his reputation as a pure mathematician tarnished.'

Virtually any physicist who has done a course in solid-state theory will have heard of the Peierls–Nabarro force, which is the force needed to move a dislocation through a crystal lattice. The idea first appeared in a paper by Peierls, which contained a mistake that Nabarro corrected; he then developed the idea much further in a succession of papers over the years. In his inimitable style, however, Nabarro writes that the concept had very little to do with Nabarro, or even Peierls, but was invented by Orowan. On the other hand, Peierls, in a letter to Nabarro dated 7 August 1989, writes: '…you not only got the answer right, but generalized it.' Elsewhere he opines that, 'It would be better if the force was called the Orowan–Nabarro Force'.

In 1948, Frank Nabarro married Margaret Dalziel, who had been Schonland's personal assistant. In the same year his gift as a bridge builder came to the fore. As Doris Kuhlmann-Wilsdorf, who was a newly minted Ph.D. in Stuttgart at the time, explains: 'In September 1948 Nabarro became one of the very first world-class scientists to visit war devastated and at the time internationally ostracized Germany, and was received with great deference.' Doris acted as his interpreter during this visit, and this was the beginning of a sequence of events that saw her joining Mott's group and sharing an apartment with the Nabarros, afterwards taking up a position in the Wits Physics Department while her husband, Heinz, became the first electron microscopist at the CSIR, and eventually ending up at the University of Virginia (UVA). As Frank and Doris ascended the firmament of science, they maintained a warm, if tempestuous, friendship. Over the years, the UVA group has had strong links with Nabarro, van der Merwe and others in South Africa, with Bill Jesser in particular making frequent visits to this country. But this is getting ahead of the story.

In 1949, Nabarro joined Birmingham University to take up a lectureship in the Metallurgy Department, which D. Hanson had built up to great strength. Here there was the strong intellectual stimulus of luminaries such as Alan Cottrell, Bruce Bilby, Jock Eshelby and Robert Cahn. During this period Nabarro put much effort into calculating the interaction of lattice vibrations and conduction electrons with dislocations, gave a formal theoretical proof of the Schmid Law of resolved shear stress in crystal plasticity, and published a long review paper on the mathematical theory of stationary dislocations, which later formed the foundation for his book. His considerable achievements by the end of this period were recognized with the conferring of an honorary D.Sc. on him by Birmingham University in 1953. After the years he had lost in the war, Nabarro was

Nabarro with Solly Zuckerman visiting Wits in 1975. Vice-chancellor Guido Bozzoli on right.

in too much of a hurry to go through a studentship and earn his doctorate the normal way.

The seminal papers he wrote in these early years are among his most highly cited, but his research output continued almost unabated throughout his life as he rose to a position of almost unrivalled leadership in his field.

The move to South Africa

In 1953, despite the gathering political storm clouds, Nabarro moved to South Africa to take up the position of head of the Department of Physics at Wits. He had an offer also from Simon Fraser University in Canada, but opted instead for Wits, attracted by the climate (the Nabarros' eldest son was asthmatic and they did not think going to damp Vancouver would be good for him) and by the presence of Schonland in the area. There were dire warnings from some of his colleagues in the U.K., but these were countered by encouragement from Alan Cottrell, who was visiting South Africa at the time and wrote that Wits operated no academic colour bar and was essentially liberal in outlook. Nabarro's intention was to stay for five to ten years, but that was not to be.

Within a few years of his arrival, Nabarro had built up the Physics Department to considerable strength. Interestingly, although he established a group working with him on the mechanical properties of solids, he did not seek to turn the department into an empire focused entirely on his area of expertise. On the contrary, through successful hiring, he encouraged the diversification of the department into magnetic resonance spectroscopy (spearheaded by Jan Loubser and later Mike Hoch), low-temperature physics (led by David McLachlan), optical spectroscopy (started by Piet Wedepohl and expanded by Darrell Comins) and theoretical physics (the first chair was held by Christian Toepffer, and Richard Lemmer was appointed to a personal chair in mathematical physics). In time there was expan-

sion into related fields such as Mössbauer spectroscopy and high-pressure physics, and condensed matter theory. Nabarro oversaw the creation of the Electron Microscope Unit, which John Mathews ran and in the process established his reputation in epitaxy. With the appointment of Friedel Sellschop as director of the Nuclear Physics Research Unit (NPRU) in 1956 (later renamed the Schonland Centre), one saw a major thrust of the department into nuclear physics open up. This was a time when nuclear physics was widely considered the panacea to all problems.

The transformation of what had previously been essentially a service department into a major research department ruffled more than a few feathers, both in the department and the university administration, and in one heated moment Nabarro threatened to resign, but wiser counsel prevailed. Over the years, the department has flourished, and still has considerable strength in the research areas opened up in those early years. Nabarro, with his puckish humour, is recorded as once saying: 'The only thing that upsets me is that the department has been doing better since I retired.'

The responsibilities of running a department, and being out of the scientific mainstream (in the days before e-mail and downloads!) did take their toll on Nabarro. Through prodigious effort he kept on the cutting edge of his field by returning to the writing of his monograph, *Theory of Crystal Dislocations*, which he had started on in the U.K., and it appeared in print in 1967. In a letter to Nabarro dated 8 March 1968, Egon Orowan writes: 'The book is splendid, overwhelming. I admire your omniscience of the subject and judgment, which puts your book on a level different from all others I know.' This was at the height of the Cold War, and Vladimir Alshits recalls how delighted they were to receive a copy of the book in his institute in Moscow at a time when there was a dearth of Western scientific literature.

As the demands of his new position eased, Nabarro was able to devote a larger portion of his time to research, and over the years contributed key ideas to many areas of dislocation physics. The period of novelty and discovery in the 1940s and 50s had by then passed, and the study of dislocations had fallen into the hands of metallurgists and materials scientists, but there were, and still are, major problems that need to be satisfactorily resolved. For example, the problem of work hardening, which is of immense practical importance, remains contentious, and it is still not possible to calculate accurately the contribution of dislocations to the electrical resistivity of metals. The difficulty stems from the complexity of dislocation networks and their interactions. In the absence of definitive answers from fundamental microscopic models, engineers have devised a multitude of parameterized empirical models that serve the day-to-day needs of the metals processing industry. Nevertheless, the search for a more fundamental understanding of the problems in this field remains very much alive. In later years, Nabarro turned his attention to quasi-crystals, dislocation patterning, and creep resistant materials and rafting in superalloys, which with H.L. de Villiers he surveyed in the monograph, *The Physics of Creep*.

Much of Nabarro's early work at Wits was done with students and young associates, including Edward Silk, Paul Jackson, John Mathews, Silvana Luyckx, Charlie Levitt, Lionel Levinson, Duncan Mitchell, Leon Vermeulen and Ewald Wessels, many of whom achieved considerable success in their careers. In spite of being a theoretician, most of the students he supervised were experimentalists. Jackson recalls that 'although Nabarro could not offer much guidance on the technical aspects of their work, he always had a good intuitive grasp of the results coming out. If an elaborate calculation had been performed, he was quickly able to recognize anything that was false.' For sure, Nabarro had an instinct for selecting students who were able and self-reliant.

Nabarro must be one of the greatest champions of experimental physics we have had. When he was negotiating to come to Wits, his primary concern was what experimental facilities there were, and what funding there would be from government and industrial sources for experimental research. Despite assurances he was given, support was slow in materializing, and in 1957 he tendered his resignation in frustration. Fortunately, he was persuaded to stay, and the situation did in time improve. The Solid State Physics Research Unit (SSPRU) was established in 1961 with Nabarro as director. Its purpose was to coordinate research activities sponsored by the university, the CSIR, Hard Metals Ltd, De Beers DRL and Iscor. From the outset, the unit's activities were divided between basic physics and projects having a direct bearing on the South African economy. There were originally three main fields of research. The first of these, the fracture of quartzite, was largely carried out by H. Schlössin and Tony Ball, but Nabarro was in close touch with their work, and involved in the supervision of the research students Ludwig Schöning and Haydée le Roux. The second, the strength of hard metal alloys, Nabarro was always closely associated with, through a life-long collaboration with Luyckx on WC-Co. The third, on diamond physics, was driven mainly by others, although there were joint papers by Urlau, Logie and Vermeulen with Nabarro. The SSPRU evolved over the years into what is now called the Materials Physics Research Institute, and has left its genetic imprint on the DST/NRF Centre of Excellence in Strong Materials.

Nabarro's involvement in dislocation physics led to two other fields of interest. The first, started out with Jackson, was in crystal whiskers, thin metal filaments which are free of dislocations and able to withstand large elastic strains. The study of the superconducting properties of strained tin whiskers led to a long and rewarding collaboration with McLachlan and Barbara Rothberg Bibby. At the same time, Alex Quintanilha was working on the theory of the interaction of crystal dislocations with lines of magnetic flux in a superconductor, while McLachlan and Terry Doyle were studying the same topic experimentally. This interest in superconductivity led Nabarro and Quintanilha to spend a few months at Orsay with de Gennes and Friedel, whose interests, by the time they arrived, had moved to liquid crystals. Undeterred, Nabarro turned his knowledge of dislocations and disclinations to this new topic, suggesting the use of the Euler–Poincaré characteristic to classify defects in nematic liquid crystals. On his return to Wits, he encouraged a succession of medical students to carry out simple but elegant experiments on disclinations in nematic liquid crystals. A further interest, stimulated by Bill Harris and Sheila Saffer, was the application of the ideas of dislocations and disclinations to biological materials. This led to an analysis of the structure of an insect muscle, which appears to have anticipated the ideas of some biologists and, during a sabbatical in Berkeley in 1977, to a successful mechanistic description of the crenation of red blood cells by drugs.

Nabarro would often give Mott's advice to young researchers: 'Try to get a mental picture of what is going on, then find the simplest theory that contains the essential facts. When things become complicated, leave the details to someone else.' He disparaged Baroque Science, a term

coined by Alvin Weinberg that refers to the pursuit of a topic to the point where it becomes preoccupied with tidying up endless minor details. Luyckx points out that, despite his encyclopaedic knowledge of his field, he knew the limits to his abilities, and was open to the contribution from other people whose skills complemented his own. This is exemplified by his collaboration with Umesh Waghmare of the Jawaharlal Nehru Centre for Advanced Scientific Research in Bangalore, India, whom he visited in May 2006, in the last months of his life. The topic of their research, modelling the slip system in WC and the influence of electric fields on stacking faults, was an area Nabarro had not ventured into before. Tiju Thomas, Waghmare's student charged with doing the computer simulations, recounts the following: 'It's an indelible impression Nabarro left on me. My perspective of science widened after meeting him. He was not just an outstanding researcher, but also an excellent student, asking pertinent questions which gave me a better view and understanding of the problem.'

Nabarro served Wits University in various capacities, including a term as deputy vice-chancellor. During his tenure in that position, in 1981 he drew up the Academic Plan, the first for any South African university, which anticipated a large influx of black students. With the aid of outside sponsors, he helped coordinate academic support activities in mathematics, science and English. His address to the December 1980 Wits graduation ceremony (*University of the Witwatersrand Gazette,* December 1980, pp. 5–8) is one of the most forceful and cogent statements one can read from that period, of the urgent need to improve the education of black children, particularly in the subject areas of mathematics and science.

Nabarro never wavered in his support for opening the doors of academe in South Africa to all who could benefit from higher education. In his graduation address to the University of Natal on 28 April 1988, he did not hide his contempt of the Separate Universities Act, saying: 'The biggest blow that the government struck at the liberal universities of South Africa in 1959 was to deprive us of our right to be … a place where men and women without regard to race and colour are welcome to join in the acquisition and advancement of knowledge'. He often voiced his belief that a university was a community of scholars, and should be governed in a collegiate way, a view somewhat discordant with today's ethos of quality control audits and the like. He argued that while universities should direct their resources towards the study of matters of social relevance, they should maintain their intellectual independence, and guard against becoming a propaganda organ for any particular political movement or party.

In his 1988 address, he relates two incidents in his life. One was when Hitler's forces were about to invade Great Britain, and his fate as a young Jew looked bleak. The other was when the South African government attacked the liberal universities. Again he decided not to run away but to stay and fight, in this case in the defence of academic freedom. In this dark hour he foresaw the politics of destructive confrontation being replaced by the politics of negotiation. He was not afraid to disagree openly with radical elements who wanted the university, in a blaze of glorious defiance, to be closed down by the police, or to take issue with the National Union of South African Students (NUSAS), when it promoted the utopian vision that the university 'should not be concerning itself with redundant measures of achievement and status such as degrees and diplomas, but be responsible for the continuing education and training of all members of society irrespective of age.'

Nabarro was an inspiring teacher and mentor. A generation of physics graduates from Wits remembers with fondness the evening sessions at his home, where the human side to physics was revealed. His lectures were challenging, and forced one to think. Through them one saw physics not as cut and dried, but as an open-ended, evolving subject.

Retirement and new opportunities

Nabarro retired in 1984, but remained an active member of the Wits community, always generous with his time and wise counsel. He devoted considerable effort to trying to persuade the university to establish a Chair of Materials Science and to seeking an endowment for this from a potential donor. Sadly, this did not come to fruition in his lifetime. In the last months of his life, he motivated for the support of biomaterials research, and chaired a meeting, called by Belinda Bozzoli, the deputy vice-chancellor for research, that brought together interested parties in Gauteng to discuss the desirability of establishing a centre of excellence in biomaterials. The outcome was extremely positive, and led to a national conference on biomaterials in September 2006, and other activities are planned. Loyiso Nongxa, vice-chancellor of Wits, in a farewell tribute to Nabarro, declared: 'He was an inspiration to generations of scientists and he had a significant influence on the thought and direction of this university. He was renowned for his brilliant mind, sharp intellect, meticulousness and his unique sense of humour.'

Nabarro was appointed a CSIR fellow in July 1994, and served up to March 2005. He was only the third such appointee to this prestigious position, which requires from the incumbent services such as enhancing the image of the CSIR, networking, technology foresight and mentoring. Bob Scholes, another fellow, has written: 'Frank was convinced that the application of systematic and scientific study to the problems of delivery of services in a democratic South Africa would greatly increase their efficiency. He cared deeply about this country, its people and their future. For all his apparent otherworldliness, some of the best lessons I learned from Frank related to the processes and politics of large organizations. He had an instinctive feeling, no doubt honed over half a century of service in many roles and committees at the university, for the nuances of bureaucratic communication and the subtle manoeuverings that go on in between the various interests in any organization. Although frequently critical of the CSIR as it struggled during the 1990s to redefine its mandate and remain viable and relevant in the New South Africa, he remained loyal to its vision: to bring science and technology to the service of the country and its people.'

He was elected to the Royal Society of London in 1971, and rendered many services. He and John Nye wrote the Royal Society *Biographical Memoir* on Charles Frank and he and Ali Argon were responsible for the *Memoir* on Egon Orowan. Under the auspices of the Royal Society, he was one of the first Western scientists to visit China after the Great Leap Forward. He was concerned that he and Phillip Tobias were the only FRSs in South Africa, and went to considerable efforts to try to get others elected. He was elected an honorary fellow of the Royal Society of South Africa in 1973 and served as president from 1988 to 1991.

Nabarro played a prominent role in the establishment of the Academy of Science of South Africa. In a letter to him dated 26 July 1994, Frederick Seitz states: 'I wish you very good luck in building up the Academy. It could play an enormously important role in the evolution of both basic and applied science in South Africa.' He was a council member of the South

African Institute of Physics for a number of years, and a vice-president from 1988 to 1991. He had a reputation in those organizations for livening up meetings with his thought-provoking views. He was a member of the Science and Engineering Academy of South Africa (SEASA), almost from its inception, lending his support to its objective to motivate underprivileged communities in the country in the acquisition of professional skills in science and engineering.

He held visiting positions at several universities in the U.S., Canada, the U.K., Germany, France, Israel and Switzerland. He was the recipient of numerous awards, including the De Beers Gold Medal of the South African Institute of Physics, the Institute of Materials Platinum Medal, the Institute of Metals R.F. Mehl Award, and several honorary doctorates. A festschrift in his honour was published by the Royal Society of South Africa in 2003, and a special edition of the *Philosophical Magazine* was dedicated to him in 2006. He was a Foreign Associate of the US Academy of Engineering, the only one on the African continent. His local stature was recognized recently with the award of the Presidential Decoration, the Order of Mapungubwe, in silver. There have been, or will be, symposia in his honour, including one in Greece in April 2007 and another planned by the international Materials Research Society for late 2007 or early 2008 in San Francisco.

Nabarro was not only an outstanding scientist, but also a well-informed and cultured man. He shared a love of classical music with his wife Margaret, who was a notable musicologist. He was honorary president of the Johannesburg Musical Society, and in memory of Margaret he established the Margaret Dalziel Nabarro Chamber Concert Fund.

He relished doing intellectual battle, and not infrequently played devil's advocate, although he would dispute that

Nabarro receiving the Order of Mapungubwe from President Thabo Mbeki.

assertion vehemently. But where there were rifts in society that he could influence, he strove to bridge them, and avoided confrontation. He had an uncanny ability to get on with people from all parts of the political spectrum in South Africa. He could visit Baruch Hirson in prison, and in the next moment conduct a discourse with the Afrikaner Nationalists directing science affairs. He strove all his life to bring theorists and experimentalists together. Already in 1987 he had approached Gordon Sibiya, the president of SEASA, with the suggestion that the Royal Society of South Africa, the Akademie vir Wetenskap en Kuns, and the Academy cooperate to form some sort of national coordinating committee. More recently, he spoke in favour of merging the Royal Society of South Africa with the Academy of Science of South Africa.

What many people admired most about Nabarro was his sheer lust for life. His energy and resilience were phenomenal, his intellectual vitality extraordinary. He travelled extensively, attending conferences and giving lectures wherever he went. He never stopped being active in research, and in the last year of his life brought out two papers, one with Shrivastava and Luyckx on 'The size effect in micro-indentation', and the other a thoughtful essay on 'Creep in commercially pure metals'. Only months before his passing, in spite of serious health problems and hobbling around painfully on a broken foot, he visited India and China. Notes on a lecture he gave, titled 'Some work on dislocations which has interested me', cover the period 1905–2006 and refer to work by David Weitz on colloidal crystals, which he could have heard of only a few days before his departure. This attests to how up to date he kept. He returned from China exhausted, but expressed the greatest delight that he had made it to Xian and seen the terracotta statues. He was editing volumes 13 and 14 of *Dislocations in Solids* when he passed away on 20 July 2006. His mind remained razor sharp to the end.

Nabarro made a fateful decision in 1953 to come to South Africa, fully aware of the political tensions that were building up. His expressed intention was to stay five to ten years, but he remained for the rest of his life. Was this a decision he ever regretted? Would his career have been even more glorious had he remained in the U.K. or gone to Canada? Certainly living in South Africa restricted his scope for research, and this by his own admission probably explains why he never drifted too far from the field of dislocations. On the other hand, he never expressed regrets for the direction his life had taken, and always projected enthusiasm and joy in everything he did. He loved company and had a wide circle of friends both in South Africa and abroad, whom he saw frequently. It must have given him such a sense of fulfilment to know how greatly he was admired in the physics community and in academe here.

Further reading

Nabarro F.R.N. (1980). Recollections of the early days of dislocation physics. *Proc. R. Soc. Lond. A* **371**, 131–135.

From locations to dislocations: Frank Nabarro turns obstructions into opportunities. An interview conducted by B. Fleischer for Profiles & Perspectives, *MRS Bulletin*, November 2004, 875–879.

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