OBITUARY: *José Enrique Moyal*

José Enrique Moyal
b. Jerusalem 1 October 1910, **d.** Canberra 22 May 1998

On Friday evening, 22 May 1998, Jo Moyal died peacefully at the Canberra Hospital, some four months short of his 88th birthday. He had not been well for some time, and had recently undergone an operation for a stone in his bile duct. He is survived by his first wife Suse, and their two children Orah and David, as well as by his second wife Ann.

Jo Moyal was born in Jerusalem, the son of David Moyal, a barrister of Tel Aviv, and his wife Claire. He was educated at high school in Tel Aviv, and later studied mathematics at Cambridge University and electrical engineering at the Institut d'Electrotechnique in Grenoble and the Ecole Supérieure d'Electricité in Paris from which he was awarded a diploma. He worked as an engineer until 1945, with an interruption of two years between 1938 and 1940 when he studied theoretical physics at the Institut Poincaré, and mathematical statistics at the Institut de Statistique of the University of Paris, from which he received his second diploma.

From 1940, he carried out research on turbulence and diffusion of gases for the Ministère de l'Air in Paris. Following the collapse of France, he escaped from Bordeaux to England as the Germans entered Paris. He had some initial difficulty in interesting the British in his skills. Eventually, he had the good fortune to be interviewed by C. P. Snow in his capacity as a civil servant, and was allocated to work at the de Havilland aircraft factory in Hatfield. He rose to be Assistant Director under R. N. Hadwin, in charge of research in the wartime department dealing with vibration and electronic instrumentation.

At the end of the war, he sought academic employment, and was first appointed as an Assistant Lecturer in the Department of Mathematical Physics at Queen's University, Belfast, towards the end of 1945. Professor P. P. Ewald, soon recognizing his ability, promoted him to a lectureship in 1946. In 1948, he was appointed Lecturer in Mathematical Statistics in Professor M. S. Bartlett's Statistical Laboratory, in the Department of Mathematics at the

https://doi.org/10.1239/jap/1032438397 Published online by Cambridge University Press

University of Manchester. In 1950 he was promoted to a Senior Lectureship. Thus began a fruitful scientific collaboration which culminated in an effort to write a Bartlett–Moyal monograph on stochastic processes. Although Moyal achieved near-completion of his part, he kept carrying out continual improvements which held up the publication of the book. Eventually, it was agreed that Bartlett should publish his part separately as *An Introduction to Stochastic Processes* (Cambridge University Press) in 1955. In its first edition, the book by Moyal was frequently cited, and referred to as 'M' in the expectation that it would soon be published. Although the notes for it still exist, the book never appeared in print, and 'M' disappeared from later editions of Bartlett's monograph.

In 1954–55, Moyal was offered a Visiting Readership in Theoretical Physics at the University of Sydney by Professor H. Messel. He returned briefly to Manchester, but then accepted a Visiting Professorship with Professor H. Robbins in the Department of Mathematical Statistics at Columbia University, New York, in 1956. He followed this with a Visiting Professorship in the Department of Mathematical Statistics under Professor J. Neyman at the University of California, Berkeley, in 1957.

In 1958, Moyal resigned from his Senior Lectureship at Manchester to take up a Readership in Professor P. A. P. Moran's Department of Statistics at The Australian National University's Institute of Advanced Studies in Canberra. His referees spoke of him in the highest terms. Professor Bartlett mentioned that on first meeting Moyal, he had been 'much impressed by his interest in, and knowledge of, the theory of stochastic processes.' Professor Robbins wrote: 'several universities of high rank in this country [USA] have offered him permanent appointment', while Sir Harold Jeffreys of the University of Cambridge thought that Moyal was 'one of the two most brilliant statisticians in England'. He added, however, 'He is unfortunately one of those people that are very reluctant to publish anything until they have done everything. The result is that he delays publication too long'. This was a characteristic which was to dog him throughout his life: Moyal had relatively few publications, but these were always thorough and complete.

He continued to work in Canberra for six years, and trained several graduate students, among them S. R. Adke, P. J. Brockwell and C. R. Heathcote, with whom he wrote joint papers. During his time at The Australian National University, he was able to persuade his Manchester colleague Professor B. H. Neumann to accept the Chair of Mathematics created in Canberra in 1962. In 1964, Moyal was appointed to the position of Senior Scientist at the Argonne National Laboratory of the US Atomic Energy Commission near Chicago, Illinois. He left this position in 1972 to join the School of Physics and Mathematics at Macquarie University, Sydney, as Professor of Mathematics, and served there until his retirement at the age of 67 in December 1977. He then moved to Canberra, where he resided for the next 21 years until his death.

Moyal's scientific work can be divided into three parts: research in (a) engineering, (b) mathematical physics including quantum theory, and (c) stochastic processes. As an engineer, he investigated the properties of rubber and rubber-like materials, as his early papers up to 1946 testify. His interest in mathematical physics is evident from his famous paper of 1949 read to the Royal Statistical Society, and in several other papers including the last two on the mathematical methods of quantum theory. He is the originator of the 'Moyal bracket' in quantum mechanics. But his main interest, as he described it himself, was the theory of stochastic processes and its applications to physical problems such as neutron diffusion and multiplication, and cascades. In particular, his papers in *Acta Mathematica* of 1957 and 1962 [22], [24] were very influential, and deserve a brief description.

https://doi.org/10.1239/jap/1032438397 Published online by Cambridge University Press

The first [22] is concerned with discontinuous Markov processes, where the state of the system may change continuously or by sudden chance jumps. Such processes are specified by two functions: the probability of a transition without jumps, and the probability distribution of the first jump time and the consequent state of the process. The total transition probability depends on both of these functions. Whereas previous work had concentrated mainly on jump processes only, Moyal was able to generalize existing results and derive new ones for the mixed case, which he analyzed with his usual thoroughness.

The second [24] provides the foundations of a general theory of population processes, in which both the number of individuals in a population and the states characterizing each of them are traced. Moyal considers point and counting processes, and develops the concept of the probability generating functional in the population context. The equivalent characteristic functional had been previously introduced by D. G. Kendall in his paper read to the Royal Statistical Society Symposium on Stochastic Processes in 1949, and further discussed by M. S. Bartlett and D. G. Kendall in *Proc. Camb. Phil. Soc.* **47** (1951) 65–76. Moyal then offers as examples of his methods, cluster processes, counting processes with independent elements, time-dependent Markov population processes, and multiplicative population processes. These papers were of fundamental importance in the history of the development of stochastic processes. Tributes from his many colleagues, and the wealth of citations to these and other of his papers, attest to the magnitude of his contribution in this field.

Moyal was an exceptionally gifted scientist, who collaborated with many of his contemporaries. In the area of stochastic processes alone, he wrote papers with M. S. Bartlett, D. A. Edwards and D. G. Kendall as well as the three students mentioned earlier. His importance as a researcher was recognized in 1997 by the award of an honorary DSc from The Australian National University. His citation for the degree of Doctor of Science *honoris causa* reads that the degree was conferred 'on the ground of his distinguished creative achievement as a scholar in mathematical statistics and mathematical physics'.

Jo Moyal was widely read in both French and English, and retained his acute intelligence and highly critical sense to the end of his life. He remained interested in world affairs and mathematical research well into his eighties. At the personal level, he had a tendency to guard his privacy closely and had only a few intimate friends. His children visited him regularly from the USA where they live, but were unable to be present at his bedside at the end. He leaves behind him a body of important fundamental work, which will continue to be mined by researchers in stochastic processes for a long time to come.

Professor M. S. Bartlett has written:

Jo Moyal was a contemporary of mine, both of us being born in 1910; but our paths did not cross until the war years, and even then at first by correspondence on our mutual interests of stochastic processes and their possible relevance to quantum theory (see my autobiographical article in *The Making of Statisticians*, ed. J. Gani, Springer-Verlag, New York, 1982, pp. 41–60).

I was greatly indebted to Moyal, not only for his own contributions, but also for his wide knowledge of the overseas literature, and we became close friends and collaborators. Professor Gani has referred to the planned (but regrettably aborted) joint publication on stochastic processes after the war; a more satisfactory cooperative venture was the 1949 Royal Statistical Society Symposium on Stochastic Processes, to which Moyal, myself and David G. Kendall (to whom I also was indebted for his important contributions to stochastic process theory) contributed. Moyal was, in addition, making some very pertinent contributions to the probabilistic interpretation of quantum theory, especially in his 1949 *Proc. Camb. Phil. Soc.* paper [10], though a final word on this fundamental topic seems to have remained elusive, even to this day.

Professor P. J. Brockwell has written:

I was fortunate enough to have Jo Moyal as both PhD adviser at the Australian National University and, thanks to his influence, as a colleague and friend at Argonne National Laboratory on the outskirts of Chicago in the late 1960s. Argonne at that time was the US Atomic Energy Commission's major research laboratory involved in the design and development of nuclear reactors, with very strong research groups in fields which included Theoretical and High Energy Physics, Applied and Computational Mathematics, and Radiation Biology. As such, it was an ideal environment for Jo, who had been sought by the laboratory because of the depth and diversity of his contributions to both physics and stochastic processes. Applications of stochastic processes in the analysis of the scattering and multiplication of neutrons in a reactor, the behaviour of high energy particles, and the multiplication of biological cells subject to radiation, were all subjects of great interest at Argonne, as was theoretical physics in general, particularly quantum field theory and the mathematical foundations of quantum mechanics. As a Senior Scientist in the Applied Mathematics Division and the leader of a small probability and statistics group, Jo became deeply involved in all of these areas and contributed substantially to the development of both the underlying theory of the stochastic processes involved and to the solution of specific problems raised by researchers in the other divisions of the laboratory.

As advisor, colleague and friend, Jo had a profound influence on my own life and work. He had an extraordinary range of interests, both professional and otherwise, and the enormous number of citations of his work bears testimony to his influence on the development of both probability and physics. It was a great source of satisfaction to Jo in his later years to know that his early work on the probabilistic foundations of quantum mechanics, particularly the 1949 *Proc. Camb. Phil. Soc.* paper [10], is currently experiencing a renaissance sparked by recent developments in theoretical physics which have made the application of his ideas feasible on a much wider scale than was originally thought possible.

Australian National University J. Gani
June 1998.

Publications

1940

[1] (with G. Debedant and P. Wehrlé) Sur les équations aux dérivées partielles que vérifient les fonctions de distributions d'un champ aléatoire. *Comptes Rendus Acad. Sci.* **210,** 243.

[2] (with G. Debedant and P. Wehrlé) Sur l'équivalent hydrodynamique d'un corpuscule aléatoire. Application à l'établissement des équations aux valeurs probables d'un fluide turbulent. *Comptes Rendus Acad. Sci.* **210,** 332.

1942

[3] Approximate probability distribution functions for the sum of two independent variates. *J. R. Statist. Soc.* **105,** 42.

1944

[4] Deformation of rubber-like materials. *Nature* **153,** 777.

[5] Rubber as an engineering material. *J. Inst. Production Engineering*, May issue.

https://doi.org/10.1239/jap/1032438397 Published online by Cambridge University Press

1945

[6] (with R. Zdanowich) Some practical applications of rubber dampers for the suppression of torsional vibrations in engine systems. *Proc. Inst. Mech. Engineers* **153,** 61.
This paper was awarded the Hubert Ackroyd Prize of the Institute of Mechanical Engineers.

[7] (with W. P. Fletcher) Free and forced vibrations in the measurement of dynamic properties of rubber. *J. Sci. Instruments* **22,** 167.

1946

[8] (with R. N. Hadwin) The measurement of mechanical impedance. In *6th International Congress of Applied Mechanics*, Paris.

1949

[9] Quantum mechanics as a statistical theory. *Proc. Camb. Phil. Soc.* **45,** 99–124.

[10] (with M. S. Bartlett) The exact transition probability of quantum mechanical oscillators calculated by the phase-space method. *Proc. Camb. Phil. Soc.* **45,** 545–553.

[11] Causality, determinism and probability. *Philosophy* **24,** 310–317.

[12] Stochastic processes and statistical physics. *J. R. Statist. Soc. B* **11,** 150–210. (Part of the Symposium on Stochastic Processes together with M. S. Bartlett and D. G. Kendall, held on June 7, 1949.)

[13] Comments on Richardson's paper on 'The distribution of wars in time'. *J. R. Statist. Soc. A* **112,** 446–449.

1950

[14] The momentum and sign of fast cosmic ray particles. *Phil. Mag.* **51,** 1058–1077.

1952

[15] The spectra of turbulence in a compressible fluid: eddy turbulence and random noise. *Proc. Camb. Phil. Soc.* **48,** 329–344.

1955

[16] Theory of ionization fluctuations. *Phil. Mag.* **46,** 263–280.

[17] (with D. A. Edwards) Stochastic differential equations. *Proc. Camb. Phil. Soc.* **51,** 663–677.

[18] Statistical problems in nuclear and cosmic ray physics. *Bull. Statist. Soc. NSW* **14,** 4–17.

1956

[19] Theory of the ionization cascade. *Nuclear. Phys.* **1,** 180–195.

1957

[20] Statistical problems in nuclear and cosmic ray physics. *Bull. Int. Statist. Inst.* **35,** 199–210.

[21] (with D. G. Kendall) On the continuity properties of vector-valued functions of bounded variation. *Quart. J. Maths* **8,** 54–57.

[22] Discontinuous Markoff processes. *Acta Math.* **98,** 221–264.

1959

[23] (with C. R. Heathcote) The random walk in continuous time and its applications to the theory of queues. *Biometrika* **46,** 400–411.

1962

[24] The general theory of stochastic population processes. *Acta Math.* **108,** 1–31.

[25] Multiplicative population chains. *Proc. Roy. Soc. A* **266,** 518–526.

1963

[26] (with S. R. Adke) A birth, death and diffusion process. *J. Math. Anal. Appl.* **7,** 209–224.

1964

[27] Multiplicative population processes. *J. Appl. Prob.* **1,** 267–283.

[28] (with P. J. Brockwell) Exact solutions of one-dimensional scattering problems. *Nuovo Cimento* **33,** 776–796.

1965

[29] Incomplete discontinuous Markov processes. *J. Appl. Prob.* **2,** 69–78.

https://doi.org/10.1239/jap/1032438397 Published online by Cambridge University Press

1966

[30] A general theory of first-passage distributions in transport and multiplicative processes. *J. Math. Phys.* **7,** 464–473.

[31] (with P. J. Brockwell) A stochastic population process and its application to bubble chamber measurements. *J. Appl. Prob.* **3,** 280–284.

1967

[32] Multiplicative first-passage processes and transport theory. *SIAM-AMS Proceedings on Transport Theory,* Vol. 1.

1968

[33] (with P. J. Brockwell) The characterization of criticality for one-dimensional transport processes. *J. Math. Anal. Appl.* **22,** 25–44.

1969

[34] Mean ergodic theorems in quantum mechanics. *J. Math. Phys.* **10,** 506–509.

1972

[35] Particle populations and number operators in quantum theory. *Adv. Appl. Prob.* **4,** 39-80.