## MARTIN DAVID KRUSKAL

Martin David Kruskal, one of the most insightful and innovative of applied mathematicians and theoretical physicists, died on 26 December 2006. During his long active career, largely at Princeton, then latterly at Rutgers University, his many honours included the National Medal of Science in 1993, the Gibbs Lectureship and the 2006 Steele Prize for Seminal Contribution to Research (both from the American Mathematical Society) and the Maxwell Prize from the International Congress on Industrial and Applied Mathematics. He was a member of the National Academy of Sciences (1980), foreign member of the Royal Society of London (1997) and of the Russian Academy of Sciences (2000) and a Honorary Fellow of the RSE (2001).

Born in New York City on 28 September 1925, he grew up in New Rochelle, New York, with two brothers destined also to become well-known mathematicians. He received his BS in mathematics from the University of Chicago in 1945, then moving to New York University for his MS and PhD under Richard Courant (a neighbour of his parents) and Bernard Friedman on `The bridge theorem for minimal surfaces'. His first employment, from 1951, was on the (classified) Project Matterhorn which aimed to use controlled nuclear fusion as a clean, safe energy source. Under the project's director Lyman Spitzer, he supplied the expertise in mathematical modelling and analysis crucial in laying down the theoretical foundations for controlled fusion and the yet undeveloped field of plasma physics. After declassification, the project became the Princeton Plasma Physics Laboratory, where Kruskal became successively Associate Head of the Theoretical Division, then Senior Research Associate, while combining his sophisticated knowledge of mathematics with strong physical intuition to develop important results both in mathematical technique and for physical application. He was prominent in devising and elucidating modern methods for asymptotics (a theme to which he returned in greater sophistication, later in his life) and, amongst results for plasma stability, for the ``Kruskal-Shafranov" criterion for kink instabilities. During this period he also introduced the Kruskal (-Szekeres) coordinates, which remove from black holes the non-physical Schwarzschild singularity.

In 1961, he became Professor of Astrophysical Sciences at Princeton, a chair which he retained when in 1979 he became Professor of Mathematics. From 1968-86, he was also Director of the Applied and Computational Mathematics program. On becoming Emeritus at Princeton in 1989, he became David Hilbert Professor of Mathematics at Rutgers University. Besides being a seminal researcher, Martin was always an enthusiastic teacher, continuing lecturing at Rutgers into the final year of his life. This enthusiasm is illustrated by the account of a graduate student, seeking a time for an appointment and receiving the reply ``How about 1 o'clock, tomorrow?" Asking whether this meant a.m. or p.m., he got the reply ``You choose, its all the same to me". His insatiable curiosity about the mysteries of the world around him and a wish to get to the essence of problems before letting logic take over in developing new theory was infectious. Perhaps the clearest illustration of this is the development of ``soliton theory", which is perhaps Martin's most all-pervasive contribution to science.

The concept of ``solitary waves" originates in Edinburgh, where John Scott Russell performed experiments in 1834 on the Union Canal at Hermiston with a view to understanding and reducing the drag on canal barges, so as better to compete against railways. Observing an occasion when the test barge decelerated suddenly, yet a great heap of water sped down the canal for two miles or more, led him to describe the `great wave of translation'. For decades this remained a curiosity, until theories developed first by Boussinesq and then in 1871 by Korteweg and de Vries allowed solitary waveforms to travel without change of shape along shallow channels. Outside hydraulics this had little significance for nearly a century. Then, Kruskal with Norman Zabusky, while performing numerical computations on an atomic lattice, noticed some remarkable collision properties of energy pulses. After multiple collisions, the pulses emerged unscathed. Despite the vast disparity of scale with water waves, Martin saw the analogy with solitary wave solutions of the Korteweg-de Vries equation, so leading him to seek an underlying mathematical explanation. Along with Princeton colleagues Gardner, Greene and Miura, he elucidated in a series of six papers (for which the 2006 Steele prize was awarded) the connection between the Korteweg-de Vries (KdV) equation (which is nonlinear, so that solutions may not be added, or `superposed') and the well-developed quantum theory, described by linear equations. They showed, using sophisticated transformations and constructions, how solutions initially described in terms of any number of non-overlapping solitary waves are described exactly, throughout their many interactions, then re-emerge as solitary waves of exactly the same amplitude and form as initially. However, the theory also gives precise formulae for the shift of the paths of the emerging pulses from the original paths. Moreover, the formalism allows construction of the most general solution to the KdV equation.

These revelations were nothing short of dramatic. Kruskal's inspired naming of the solutions as `solitons', combined with the intrinsic elegance of the predictions led to a veritable explosion of activity. Within very few years, a stream of results from eminent scientists in the U.S.A., Soviet Union, Japan, Italy, Britain and many other countries not only extended the theory, but also showed that the soliton property was not unique to the

KdV equation. Between them, equations possessing the `complete integrability' property were soon shown to have relevance in many branches of physics, in chemistry, in bio-molecules and in telecommunications. Moreover, by showing that nonlinear partial differential equations need not be intractable, soliton theory has stimulated vast activity in `integrable systems theory', which both exploits powerful, but half-forgotten, results from a century ago and continues to generate deep new connections with geometry and classical analysis, aided by powerful modern computation.

One such semi-classical body of results is due to Painlevé (after whom a square beside the Sorbonne is named). Seeking differential equations from a certain class, which possessed a certain analytic property, he and his students identified before World War I six which could not be related to those already discovered, named and studied. Solutions to the new equations were called `Painlevé transcendents', but remained only partially understood. However, Martin saw their relevance as solutions to similarity reductions of equations possessing solitons, thereby frequently describing the long-time behaviour. Conversely, if an equation passed a `Painlevé test' it was shown to be a good candidate for possessing the `soliton property'. This provoked two important lines of investigation, characterizing Martin's drive to develop transparent methods for revealing hidden structure. By generalizing the Painlevé test to partial differential equations, Martin stimulated another field of intense activity, since the test was seen to be more methodical to apply than many previous techniques. Also, in seeking a procedure more direct than the essentially algebraic one due to Sophus Lie for identifying all similarity reductions of a partial differential equation, he devised with Peter Clarkson an extremely efficient and remarkably direct method. Surprisingly, this not only saved much labour, but for a few well-known equations revealed possibilities not predictable using Lie's method. The method has not only become widely used, but its surprise predictions have also provoked reappraisal of classical methods. Peter's story that their method was devised essentially during a seven-hour car journey across New Mexico illustrates the remarkable alertness of Martin's mind - an alertness well known to all those who attended conferences and workshops at which he was present, wearing one of his mathematically-inspired T shirts, carrying his knapsack and shooting out penetrating but helpful questions!

In his emeritus years he reinvigorated asymptotic analysis, being a major contributor to the development of exponential asymptotics, which explains the often subtle effects missed by more standard procedures. His enquiring mind also became fascinated by `surreal numbers' (which include both exponentially small and exponentially large numbers) discovered by Conway. To this beautiful topic, he has contributed much insight and defined various operations which he hoped would lead to a calculus for surreal numbers. He continued to travel widely as invited participant at research meetings and was a frequent visitor to Scotland, especially to Heriot-Watt University, which awarded him an honorary DSc in 2000; indeed he was a lead speaker at a meeting there only a month before the first of two strokes which led to his death. To the many who worked with him, his loss is deeply felt, while the wide community which he influenced will miss his many penetrating insights.

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