BIOGRAPHICAL MEMOIRS OF — FELLOWS OF THE ROYAL SOCIETY

Fritz Joseph Ursell. 28 April 1923 — 11 May 2012

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Elected FRS 1972

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Fritz Ursell was a singular and influential applied mathematician. He made seminal contributions to research in the mathematical analysis of linear water waves. This required the development of new techniques for the asymptotic evaluation of integrals, especially uniformly valid approximations. He made numerous contributions to the field; for example, he constructed a family of solutions for edge waves on a sloping beach that extended Stokes's original result, he gave a detailed analysis of the Kelvin ship-wave pattern, and he was the first to prove the existence of trapped modes in water-wave problems.

Fritz was educated at Cambridge and then worked for Group W at the end of World War II, devising methods for ocean-wave forecasting. After three years in Manchester as a Research Fellow with Sydney Goldstein FRS, he returned to Cambridge in 1950 as a university lecturer. In 1961 he was appointed to the Beyer Chair of Applied Mathematics at the University of Manchester, a position he held until his retirement in 1990. His papers, collected and published in 1994, are exceptional for their clarity and precision.

Although quiet and modest, Fritz was a charming, witty and popular colleague. He was especially well read on matters of politics and history. Fritz was strongly committed to the traditional values of collegiality and academic excellence, and gave generously of his time and influence to assist others, especially younger researchers.

Early years

Fritz Joseph Ursell was born in Düsseldorf, Germany, on 28 April 1923. His father, Dr Siegfried Ursell, a paediatrician, served as a doctor in the German Army throughout World War I. Fritz's mother, Leonore Helene, *née* Mayer, had trained as a kindergarten teacher before

the war and worked as a hospital nurse during the war. The families of both parents belonged to the German–Jewish bourgeoisie and had been settled in western Germany for centuries.

On 30 January 1933, when Fritz had almost reached the age of 10 years, there was a change of government in Germany: Hitler attained power. Fritz had four Jewish grandparents, and so he was to be excluded from secondary schools. Education abroad was not feasible because money could no longer be transferred to foreign countries. However, it turned out that Fritz was in a privileged category because his father had served in the front line during the war. Thus, in April 1933, Fritz joined the Comenius Gymnasium (Grammar School). There he learned much Latin and Greek, but the mathematics was uninspiring and did not interest him. He remained in the school until December 1936; life there became more and more difficult because he was the only Jewish boy in the school.

In 1936 Fritz's mother was in touch with her cousin Dr Adolf Schott, a physician working in London, and also with Jeannette Franklin Kohn, a former resident of Düsseldorf. Jeannette was a member of a distinguished Anglo-Jewish family who had married Fritz Kohn, a German Jew. The Kohns were in England, and Jeannette was indefatigable in her efforts on behalf of German–Jewish children. A place was found for Fritz at a Preparatory School, Streete Court School at Westgate-on-Sea, Kent, and so Fritz started there in January 1937. By June he had learnt enough English to take the Common Entrance Examination into Clifton College, Bristol.

Fritz passed into a high form; he attributed his success to his knowledge of Latin. He progressed rapidly in mathematics and did well in the School Certificate in December 1938. Then, under the English system, Fritz had to specialize: he had permission to stay in England but only for the purpose of education. His parents (still in Germany) were told by the Clifton Head of Mathematics, H. C. Beaven, that Fritz might have a good chance of getting a university scholarship in mathematics later, and so they reluctantly decided that he should go in for mathematics. It was a subject in which they could not foresee a career.

In January 1939 Fritz joined the Mathematical Upper Fifth at Clifton College. The teaching was on an individual basis: he worked through textbooks and exercises at his own pace. The aim was to prepare for taking the Higher School Certificate in June 1940. His subjects were scholarship mathematics, scholarship physics (which he did not enjoy), subsidiary English, subsidiary Old Testament and subsidiary German language (without preparation).

Meanwhile the situation of the Jews in Germany was getting worse. Fritz's father had lost the right to practise as a doctor, and he applied for an American immigration visa. Having obtained permission from the British government, he came to England with his wife and daughter to wait for their visas. Then war broke out, and the Ursells became enemy aliens. In May 1940, after the fall of France, Fritz was given notice by the police that he would have to leave Bristol, which was near the coast, and so that seemed to be the end of his scholarship ambitions. However, the headmaster of Clifton, B. L. Hallward, found him a place at Marlborough College. He joined the Mathematical Upper Sixth. The Head of Mathematics was Alan Robson, a famous teacher and writer of some excellent textbooks (with C. V. Durell of Winchester College). Fritz took the Higher School Certificate that summer, with distinction in mathematics and physics.

The Cambridge Scholarship Examinations were due in December. Robson advised Fritz to apply to Trinity College. He knew that Fritz had no financial means, that a scholarship would pay for half his expenses, and that Trinity had the resources to pay for the rest if they so wished. This is exactly what happened. Fritz was elected to a Trinity Major Scholarship in December 1940; his best subject was projective geometry.

Cambridge, 1941–43

In January 1941 Fritz went up to Trinity, in mid-year as was not unusual during the war. The academic year consisted of three full terms of eight weeks each, less than half a year in total. For this period the cost of tuition, board and lodging was £180. Scholars going up in October usually went into the second year; Fritz was told to go to second-year lectures but to take the first-year examination, and then to go on to the third-year lectures.

Fritz took Part I of the Mathematical Tripos and then, in October 1941, he began the Part II course. His Director of Studies was A. S. Besicovitch FRS. Fritz did well and was elected to a Trinity Senior Scholarship. He obtained permission from the Ministry of Labour and National Service to go on to the third year. Accordingly, he started the Part III course in October 1942.

The classes were very small, with five students: Freeman Dyson (Trinity, from Winchester; FRS 1952), James (later Sir James) Lighthill (Trinity, from Winchester; FRS 1953), Tony Skyrme (Trinity, from Eton), Alison Falconer (Newnham) and Fritz. With characteristic modesty, Fritz always claimed to be the weakest student. In fact, he was worried about not being able to compete against his talented fellow students, and so he went to Besicovitch. Fritz liked to recount the advice he received: 'You will never have to compete, these talented people will not be interested in your problems but in different problems. Also, they may abandon mathematics altogether, like the famous Trinity mathematician Isaac Newton. And finally, it is not the good mathematicians who do the good mathematics.'

Fritz attended lectures from Besicovitch on sets of points, G. H. Hardy FRS on divergent series, J. E. Littlewood FRS on complex analysis, A. E. Ingham (FRS 1945) on number theory, W. V. D. Hodge FRS on Riemann surfaces, and P. A. M. Dirac FRS on quantum mechanics. He took the Part III examinations and obtained a distinction.

Group W, 1943–47

Late in 1943, Fritz was interviewed by a visiting committee of three, including Sir Henry Thirkill and the novelist C. P. Snow. Its purpose was to put him into some suitable establishment of the Scientific Civil Service, where he would be able to contribute to the war effort, as he was keen to do. He was asked whether he thought himself as good as Lighthill and Dyson: he did not! The committee recommended that Fritz should go to the Royal Aircraft Establishment, Farnborough, but they would not take an enemy alien (as Fritz was classified).

Instead, in December 1943, Fritz was posted to the Admiralty Research Laboratory (ARL) at Teddington in southwest London. He was appointed to the grade of Temporary Experimental Officer at an annual salary of £275. He started in Group H (Electromagnetics) as an assistant to A. Craig, measuring photographs of trajectories of model torpedoes that Craig fired into a water tank. The head of Group H at that time was S. Butterworth. In May 1944 Fritz was told that Butterworth would soon retire, that a new research group (Group W) would be set up, and that it would take over the office that Fritz was sharing with several colleagues. There was no room for Fritz in the reduced space allocation assigned to Group H, and so Butterworth suggested that he should simply stay in his old office.

In this way, Fritz joined Group W (the Wave Group) in June 1944, thus serendipitously determining his subsequent career.

The landings in Normandy took place in June 1944. Wave forecasts were made for these: Allied troops had to set down safely on beaches. The forecasts were accurate because the local waves were generated by the local weather; distant weather had little effect. For the landings in Japan, due in 1946, the waves on the beaches would be due to ocean swell generated by distant storms. Determining rules for forecasting these waves was the task given to Group W.

The newly appointed head of Group W was George Deacon (FRS 1944), recently transferred to Teddington from anti-submarine work in Scotland. Other members included N. F. Barber, J. Darbyshire, C. H. Mortimer (FRS 1958) and M. J. Tucker. How were they to discover appropriate rules for wave forecasting? This was a challenging task for a group of whom some (including Fritz) had no previous research experience.

Deacon put all of the group into one large room on the top floor of ARL, with his desk at one end and the junior draughtsman's drawing board at the other; there were no partitions and no obstacles to discussion, but no ideas resulted. 'Deacon came to the conclusion that it would be good for us to experience some real sea, so he packed us off to the Cornish coast where there were still some wave recorders in action' (Darbyshire 2003). Barber, Darbyshire, Ursell and two assistants drove to north Cornwall and took measurements for a few weeks; no useful results emerged. On their return, Deacon did not ask them to write a report showing at length that they had found nothing. They kept on talking to each other. Fritz began to read Sir Horace Lamb's *Hydrodynamics* (Lamb 1932), especially chapter 9 on surface waves, where the Cauchy–Poisson problem was discussed in detail.

Cauchy and Poisson (independently in 1815) considered the waves generated by an instantaneous localized disturbance: these are circular ring waves of all possible wavelengths, long waves travel faster than short waves, and an observer on a distant shore will first see long waves of long period, then progressively shorter waves of shorter period. Each period travels outwards from the centre with a characteristic velocity, the phase velocity. A disturbance over a finite area and lasting a finite time will similarly give rise on the shore to a spectrum of frequencies changing with time.

Fritz suggested that they should measure the variation of frequency with time in Cornwall and try to trace the waves back in space and time and see whether they did indeed originate in a region of high wind. He wrote a short ARL Report (dated March 1945) explaining these ideas.

The experiments were done: they used a submerged pressure-measuring device every two hours to take a 20-minute record of the pressure due to the waves. Next, they needed to make a Fourier analysis of each record, extracting about 120 harmonics. Barber designed a method whereby such a spectrum could be found in 20 minutes. Each record was laid along the rim of a large heavy wheel and then read optically by a single tuned circuit. The wheel was speeded up to four revolutions per second and then left to slow down under friction; as it did so, the various Fourier frequencies successively came into resonance with the tuned circuit, and the output of the circuit gave the amplitudes.

Then they traced frequencies backwards from the beach by using the known theoretical group velocity, and showed that they originated in a storm area. The conclusion is that, outside the storm area, waves really do propagate according to linear theory.

While the group members were conducting their analyses, the war against Japan ended. However, government policy dictated that Fritz had to stay in the Admiralty until 1947.

Barber and Ursell drafted a long paper (2)*, which was rewritten by Deacon. According to Admiralty rules the sole author on the title page should have been Deacon, but he refused to have his name mentioned. He behaved similarly when receiving distinguished visitors; there were many, including Sir Henry Tizard FRS, Sir Frederick Brundrett and Harald Sverdrup. Deacon would present the group's methods and then finish by saying, 'Of course you must realize that I was merely the administrative director. This work was done not by me but by A, B, C and D' (and then he would mention all their names). The visitors would gaze at him in astonishment. Deacon later became the first Director of the National Institute of Oceanography.

Years later, Fritz had this to say about Norman Barber (18):

> He was a true physicist, with physical insights which (as I then discovered) differ greatly from mathematical insights. … Of all my colleagues he had the most profound influence on me. For me he was the closest approximation to a thesis supervisor, for I never was a graduate student. We remained in touch until his death in 1992.

Fritz decided that he did not want to be an oceanographer, but he stayed in Group W and worked on the motion of ships in waves. Partly inspired by Georg Kreisel (FRS 1966; another Trinity mathematician), he began to work on boundary-value problems in the linear theory of water waves. He rediscovered the wavemaker theory of Sir Thomas Havelock FRS (as Havelock told him after Fritz had sent him a report), and then he used it to find the reflection from a thin vertical barrier (1).

Fritz next considered the heaving and rolling motions of horizontal cylinders in the free surface of a liquid. For the heaving (vertical) oscillations of a half-immersed circular cylinder, he represented the velocity potential, ϕ, in terms of a wave source and an infinite series of wavefree potentials (3). This new method led to an infinite system of linear algebraic equations with explicit coefficients. Its solution was computable by the methods available in 1947 and, in fact, they were actually used (by the Mathematics Division of the National Physical Laboratory) to compute for the first time the added mass and damping as functions of frequency. Fritz's 'multipole method' was developed and used extensively by others (including Havelock (1955)). Fritz chose to review it 40 years later in his Georg Weinblum lecture (16):

> We have now seen that the multipole expansion
>
> $$\phi = \text{wave source plus wavefree potentials}$$
>
> can be justified mathematically but some ship hydrodynamicists have regretted that this expansion has no obvious physical interpretation. It is precisely for this reason that we need the mathematical justification which shows that the series is justified if and only if the original linear frictionless model is justified.

Fritz's work attracted the attention of the Admiralty's Assistant Director of Research in London, and Deacon was questioned about it at one of their monthly meetings. The Assistant Director complained that Fritz's mathematics was unintelligible to him, but Deacon told him that it was of great value, and his view prevailed because of his prestige as a Fellow of the Royal Society. When he returned from London he told Fritz that his work was now permitted but added: 'I did not tell the Assistant Director that I also do not understand your mathematics'.

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* Numbers in this form refer to the bibliography at the end of the text.

Manchester, 1947–50

By late 1946 Fritz was unsure of what to do next. He acquired British nationality and was appointed to a permanent position in the Scientific Civil Service. He submitted a Trinity Fellowship thesis, and soon afterwards it was suggested to him by G. N. Ward, who had moved from the Admiralty to Manchester University, that Fritz should apply for a vacancy there. Fritz went for an interview in Manchester, staying the following night at Sydney Goldstein's house. There, Goldstein dictated a letter in which Fritz made a late application for an Imperial Chemical Industries (ICI) Fellowship, which he duly received. It was a three-year lectureship with reduced teaching duties and a generous annual salary of £550. Fritz always described this as 'probably the best job I ever had'. Although the Fellowship was financed by ICI, the company did not ask for any direct benefit in return.

Fritz moved to Manchester in September 1947. Almost immediately he was also elected to a Prize Fellowship at Trinity, for four years, a prestigious appointment. At that time, the Mathematics Department at Manchester was becoming one of the world leaders. Its Professor of Applied Mathematics was Goldstein; Lighthill was a Senior Lecturer, R. E. Meyer was the other ICI Fellow, and other members included Charles Illingworth, F. G. Friedlander (FRS 1980), D. S. Jones (FRS 1968) and G. N. Ward. Manchester also had better facilities than those at Cambridge (such as offices for its staff; Fritz shared one with Richard Meyer). Fritz therefore chose to stay in Manchester and was granted leave of absence by Trinity.

The Professor of Pure Mathematics at Manchester was Max Newman FRS, who had lectured to Fritz in Cambridge and had gone from there to Bletchley Park. There were quite a few PhD students, who were housed in large lecture rooms and gave assistance to each other. The pure seminars were attended by the applied mathematicians, and the converse was also true. Fritz observed that Lighthill was able to comment on every topic, and this encouraged him to broaden his interests. The principal fields of research at the time were atomic energy and supersonic aerodynamics. Fritz decided to join the aerodynamicists and wrote two papers in that area, but then he decided to return briefly to his research on water waves. He never returned to aerodynamics, and there was no pressure on him to do so.

The mathematicians met for coffee in the morning and tea in the afternoon, and—most importantly—for lunch in the refectory, always sitting at the same table, which they shared with the physicists. The professors had their own table, but the senior professor of physics, P. M. S. (later Lord) Blackett FRS, chose to sit with them. Coffee after lunch took place in the staff common room, where mathematical problems were often discussed. Goldstein would also bring back current problems from meetings of the Aeronautical Research Council.

During this period Fritz wrote three important papers on water waves in the presence of a submerged circular cylinder. One motivation was the work of W. R. Dean (a lecturer at Cambridge, 'endowed like Stokes with a well-developed gift of silence' (Binnie 1978)) on the reflection of a normally incident wave by such a cylinder. Dean found that the reflection coefficient (a function of two dimensionless parameters) was always zero. Could this be correct? Dean's 'argument was incomplete' (one of Fritz's favourite euphemisms). Fritz used a different method and proved that Dean's result was correct ((4), part I). He also proved a uniqueness theorem for this special geometry ((4), part II). The third paper (5) contained an existence proof for a trapped or localized mode. Such modes are finite-energy non-trivial solutions that exist in the absence of forcing. Stokes had found such a solution (an 'edge wave') for a sloping beach in 1846, and Fritz would soon generalize the Stokes solution.

CAMBRIDGE, 1950–61

In 1950 Fritz was offered a University Lectureship in Applied Mathematics at Cambridge. He had many misgivings about accepting the post. The Cambridge Faculty of Mathematics had no premises. Where would he work? How would he meet other applied mathematicians, who were dispersed over the Cambridge colleges? Would it not be better to stay in Manchester? At this point he consulted Sydney Goldstein, who told him that he was leaving Manchester to go the Haifa Technion, Israel, and he invited Fritz to go with him. Fritz would say later that he 'had lived in difficult conditions since 1933, and he now wanted a quiet life': he accepted the Cambridge post. His mother and sister were also living in Cambridge (his father had died in December 1947), and he moved in with them.

Soon after his arrival in Cambridge, Fritz was having dinner in Trinity (he was still a Fellow) when he was approached by Sir Geoffrey (G. I.) Taylor FRS, Yarrow Research Professor of the Royal Society. Taylor told him that he had seen the paper on trapped modes (5), but he insisted that the work needed to be completed and that Fritz would need to do some experiments. When Fritz expressed doubts about his experimental abilities, Taylor brushed them aside: he would provide the equipment, he had a wave-tank that had been used by him in 1936 for the Christmas Lectures at the Royal Institution, and he would put this back in his laboratory. Of course, G. I. Taylor was a scientist of the highest distinction, and by permission of the Cavendish Professor of Physics, Sir Lawrence Bragg FRS, he occupied two medium-sized laboratories in the Old Cavendish Laboratory designed by Maxwell. One of the laboratories served as a workshop, with a few machine tools. This is where Taylor usually worked, at a stone window bench, part of Maxwell's design. The other laboratory contained a wind-tunnel in which A. A. Townsend (FRS 1960) and his students did their work on turbulent shear flow. The wave-tank duly arrived and was put on the same steel frame as the wind-tunnel and could therefore be used only when the wind-tunnel was not running. A table was also found for Fritz next to the wind-tunnel and next to the remains on the wall of Taylor's famous rotating-cylinder experiment. (Townsend (1990) and J. S. Turner (FRS 1982) (Turner 1997) have described the Taylor laboratories at this time, Townsend noting that Fritz 'inserted himself into the wind-tunnel room' and Turner noting that Fritz's desk was 'reached by climbing under the wind tunnel'!) Fritz received much help in the design of his experiment from Townsend and his associate T. H. Ellison. His earlier work on trapped modes had been concerned with submerged circular cylinders, but the experiment dealt with a sloping beach, for which the simplest trapped mode was the well-known Stokes edge wave (see Lamb (1932), p. 447). If the beach is given by $y = -x \tan \beta$, with the edge at the origin and y pointing upwards, the Stokes solution for the velocity potential is

$$\phi = \exp\{x \cos \beta - y \sin \beta)\} \cos(kz - \omega t),$$

where the z axis is along the edge, and $\omega^2 = gk \sin \beta$. Fritz discovered that the Stokes edge wave was the first member of a sequence: for any angle of slope β there is a finite number of edge modes, and a new mode appears (is cut-on) when β is 30°. At this angle the new mode is dominated by viscosity. As Taylor had expected, Fritz learnt a great deal from his experiments, extending the theory and finding good agreement with the experiments (6). The new modes exist when $\omega^2 = gk \sin(2n + 1)\beta$, with $(2n + 1)\beta \leq \pi/2$ and integer n; $n = 0$ gives the Stokes edge wave, with more modes appearing when β becomes smaller. Fritz simply wrote down the solution for ϕ as a certain linear combination of $2n + 1$ exponentials with coefficients given as

the product of *n* ratios of tangent functions. It turns out that edge-wave solutions are important in understanding near-shore beach processes, such as rip currents and sedimentology.

In 1951 Fritz went to Washington DC for a conference on gravity waves at the National Bureau of Standards. He also visited Harvard (G. Birkhoff), New York University (R. Courant, K. O. Friedrichs, F. John and J. J. Stoker) and the Scripps Institution of Oceanography (C. Eckart), and he met Arthur Ippen from the Massachusetts Institute of Technology (MIT). These contacts would prove valuable later. One fruit of these visits was a paper (7) containing what is now known as the Ursell number, $U = A\lambda^2/h^3$, which is of basic importance in the theories of long waves on water of depth *h*; the waves have length λ and amplitude *A*. Such theories assume that h/λ and A/h are small, but Fritz showed that the size of $U = (A/h)/(h/\lambda)^2$ is crucial: linear shallow-water theory is appropriate when *U* is small, whereas nonlinear theories are required for larger values of *U*.

Fritz's original method for determining the wave field emanating from oscillating cylinders does not work well when the frequency becomes large. Studying this limit led him to new methods for short-wave problems and to his interest in integral-equation methods, following earlier work by Fritz John (John 1950). Thus, for the half-immersed circular cylinder, there is a dimensionless parameter *Ka* (where *a* is the cylinder radius and *K* is the free-surface wave number), and the aim is to solve as $Ka \to \infty$. The problem is set up as a boundary integral equation for the velocity potential on the semicircle at angle θ, $\phi(\theta; Ka)$; a limiting value, $\phi(\theta; \infty)$, is expected but this is difficult to show. Fritz notes that one can derive many different integral equations for $\phi(\theta; Ka)$ by changing the fundamental solution used, and then he shows how a particular choice leads to an integral equation that behaves well as $Ka \to \infty$. Rigorous high-frequency asymptotic approximations are then obtained (8). The idea of using non-standard fundamental solutions has turned out to be very fruitful, both theoretically and numerically. Fritz himself used his idea (he called it a trick) in several later papers. In fact, in his last published paper (19) he wrote as follows:

> It is reasonable to hope that there are many problems for which we may gain physical insights by studying their mathematical solutions. However, in reviewing my own work I find that I have often not been able to attach a physical meaning to the most essential parts of the mathematical argument. On the contrary, almost every solution has required some special mathematical trick which appears remote from the physical aspects of the problem, in many cases an asymptotic trick.

Asymptotic tricks for rigorous short-wave approximations were developed by Fritz for transmission of water waves past a half-immersed circular cylinder (14) (the transmission coefficient is very small, of order $(Ka)^{-4}$; the 'calculation is somewhat formidable' (17)) and for problems in acoustics (11) ('without doubt the most difficult piece of mathematics which I have so far undertaken' (17)).

Fritz's 1954 paper with T. Brooke Benjamin (FRS 1966) is his most cited publication (9). It concerns the stability of the free surface of a tank of liquid that is oscillating vertically (Faraday's problem). In effect, gravity is augmented by a periodic term, and this leads to Mathieu's equation for the time-dependent amplitudes of the free-surface modes.

At Cambridge, Fritz began to supervise PhD students. They were E. F. Bartholomeusz (1955), R. C. Thorne (1955), V. C. L. Hutson (1958), A. M. J. Davis (1963), R. L. Holford (1963) and E. O. Tuck (1963), the last three obtaining their degrees after Fritz had moved back to Manchester. In *The life and legacy of G. I. Taylor* (Batchelor 1996), George Batchelor FRS included a photograph of the Fluid Dynamics Group in the Cavendish Laboratory taken in

April 1955 (Figure 16.2 on p. 226); it shows Bartholomeusz, Thorne, Hutson and Fritz. (The same photograph is in Turner's paper (Turner 1997).)

In 1955 Fritz 'was invited by George Batchelor to contribute to a work which [they] intended to present to G. I. Taylor on his 70th birthday. [He] decided to take the opportunity to write an article about wave generation. … I found it more difficult to write than any of my other papers' (18). Its opening sentence is 'Wind blowing over a water surface generates waves in the water by physical processes which cannot be regarded as known' (10). His thorough review concluded 'that none of the existing theories was adequate, and publication was quickly followed by the theories of O. M. Phillips and J. W. Miles, which have so greatly contributed to our knowledge though they may not be the final answer' (17).

Fritz spent the academic year 1957–58 at MIT, in Arthur Ippen's Hydrodynamics Laboratory (Department of Civil and Sanitary Engineering). He worked with graduate students (R. G. Dean and Y. S. Yu) and gave lectures. It was there that he first met J. N. Newman, another student. Newman obtained permission to spend the following year with Fritz in Cambridge. The three students mentioned were advised by Fritz and obtained their degrees from MIT, Dean in 1959, the other two in 1960. Bob Dean was also assigned by Ippen to help Fritz buy a car and to teach him how to drive ('a very harrowing experience'). Fritz also met his future wife, Katharina Renate Zander, during a visit to New York. Fritz and Renate were married on 19 June 1959, and they had two daughters, Ruth and Susie.

Fritz's interest in obtaining asymptotic approximations of functions defined by integrals dates to this period and was motivated by a study of Kelvin's ship-wave pattern (13). Thus, consider $\int g(z,\alpha)\exp\{Nf(z,\alpha)\}\,dz$ when $N \to \infty$, where α is a parameter. Such integrals can be estimated by the method of steepest descents, but the problem is to obtain uniform estimates with respect to α. The standard difficulty occurs when two saddle points (where $\partial f/\partial z = 0$) coalesce as α approaches a critical value. The trick is to introduce a new variable, u, related to z by a cubic equation, $f(z,\alpha) = u^3 - uA(\alpha) + B(\alpha)$, with certain choices for A and B. One then has to show that the mapping from z to u is invertible near the saddle points. This was proved independently by Chester and Friedman, and by Ursell in their joint paper (12); Fritz's proof is the one using the Riemann surface. The paper is regarded as fundamental in the development of uniform asymptotic expansions; see, for example, section 2.4(v) of Olver *et al.* (2010). Commenting on its impact on his own work, Sir Michael Berry FRS wrote to one of us (I.D.A.) as follows:

> My first papers, in the 1960s, were applications of [(12)] to integrals representing scattering in quantum mechanics. Then in the 1970s, when singularity theory provided a hierarchy of structurally stable polynomials representing caustics, I generalized the method in [(12)] to get uniform approximations for wave problems. I have used the method for a number of problems since, and developed the related high-order asymptotics with Christopher Howls. These efforts culminated in chapter 36 of Olver *et al.* (2010), where we list known properties of these 'diffraction catastrophes' (now standard special functions), and describe their use as the skeletons of uniform approximations.

On several papers from this period, such as (10), (11) and (12), Fritz gives his affiliation as King's College, Cambridge. That was because he was the Stringer Senior Research Fellow in Natural Sciences at King's, 1954–60.

In 1958 Fritz obtained a DSc degree from Cambridge. His motivation to submit for the degree (he had already published about 25 papers) was the perceived importance of having a doctoral degree within the American academic system.

MANCHESTER, 1961–90

In 1961 Fritz was offered the Beyer Chair of Applied Mathematics at Manchester, in succession to James Lighthill, who had resigned to become Director of the Royal Aircraft Establishment at Farnborough. Fritz sought G. I. Taylor's advice: should he accept the offer and, if so, should he feel obliged to take on any administrative roles? Taylor's advice was that Fritz should not feel any such obligation and that he should accept the position, but he added 'whatever decision you make, there will be times when you regret it' (Turner 1997).

To complicate matters, Fritz was also offered a professorship at MIT. After lengthy deliberations, Fritz accepted the Beyer Chair and moved back to Manchester, remaining there for the rest of his career. He maintained his research productivity, perhaps because he did not take on any major administrative roles within the Department of Mathematics or the university. (He was always grateful to Charles Illingworth and Lesley Camm for shouldering most of the department's administrative burden.) Fritz graduated 13 PhD students: F. G. Leppington (1964), D. V. Evans (1966), R. D. Gregory (1967), P. F. Rhodes-Robinson (1967), M. W. Green (1969), S. J. Maskell (1969), F. Khalil (1970), J. Martin (1973), P. G. Sayer (1977), A. Hulme (1981), A. P. Burrows (1983), P. Walton (1986) and E. A. Chadwick (1992).

Starting in the early 1960s there was an effort to extend slender-body theory from aerodynamics to ship hydrodynamics. Fritz wrote several papers on this topic, including his first paper at Manchester. It turned out that the application to ships was disappointing in its predictive power, but more elaborate forms, using 'strip theory', do better. In strip theory, each section of the ship is treated as if it were a piece of an infinitely long cylinder of the same cross-section. This motivated Fritz's interest in the diffraction of waves at oblique incidence to such a cylinder. He also investigated the problem of 'head seas' in which, far from the cylinder, the wave crests are perpendicular to the generators of the cylinder. He showed that such a wave motion is impossible: waves are refracted away from the cylinder.

Transient water-wave problems were the subject of a 1964 paper. Imagine displacing a floating body from its equilibrium position and then letting it go. One might expect (as Fritz did) to see damped harmonic oscillations, but the decay is shown to be ultimately algebraic. Further analysis and numerical computations were performed later with Maskell.

Fritz's 1984 paper with M. J. Simon (15) gave the first significant generalization of Fritz John's uniqueness theorem (John 1950) for two-dimensional floating-body boundary-value problems. Much further work followed by others.

Fritz wrote many papers on 'integrals with a large parameter'. These are mainly technical in nature, they often involve a trick of some kind, and they were often motivated by problems brought to his attention by colleagues, students or participation at conferences. Ideally, he should have written a book on asymptotics, but he never did: he always claimed that he could not write a research monograph because he did not know what other people had done. (When Fritz retired in 1990, he had accumulated more than 10 000 papers in dusty filing cabinets; the drawers were seldom opened, except by treasure-seeking students.)

Concerning conferences, Fritz was a regular participant at the International Workshops on Water Waves and Floating Bodies. These annual meetings were started in 1986 by David Evans and Nick Newman to reflect the spirit of his ideals, by bringing together both estab-

Figure 1. Photograph taken at the 15th International Workshop on Water Waves and Floating Bodies, Caesarea, Israel, 2000. From left to right: C. M. Linton, B. Shipway, D. V. Evans, E. O. Tuck, J.-M. Vanden-Broeck, F. Ursell, R. Beck and J. N. Newman. (Online version in colour.)

lished and younger workers in an informal setting (figure 1). Fritz was stimulated by the workshops; he was always interested in new problems where his skills could be exercised and developed. For example, he became interested in methods for calculating the Kelvin source, trapped modes, and the Cauchy–Poisson problem for water of finite depth.

Having reached the age of 67 years, Fritz retired from the University of Manchester in 1990. The occasion was marked by a two-day conference in Manchester. Fritz gave the last talk, 'Some unsolved and unfinished problems in the theory of waves'; it is contained in the proceedings of the meeting (17). In 2008 a short meeting in Manchester marked his 85th birthday. Fritz spoke, combining reminiscences with his observations on the state of universities.

CLOSING REMARKS

We have written mainly about Fritz and his mathematics, but he was more than just a fine mathematician. He will be remembered for his humanity, for his wit, and for the time he was prepared to spend with colleagues, especially young researchers. He was a natural raconteur able to converse in an engaging manner on a wide range of topics, his favourites being history and politics. Fritz was an active participant in university politics, fearful of the progressive intrusion of market and business ideology into the ethos of university life. He strove valiantly to oppose the transition from a collegial to a management style of university government, although he recognized that it was a losing battle. In his 2008 lecture, Fritz warned that 'recent university reforms … have increased the control of government over the research done in universities'. He was tireless in drawing attention to the negative impact of these changes, in speeches to university bodies and in letters to university administrators. Fritz often championed the cause of the non-professorial staff. He had a strong sense of fairness and was not afraid to stand up for those who he thought were being treated unjustly, perhaps because he had suffered grave injustice in Germany in his early life. We can hardly do better than close with one of Fritz's signature remarks: 'All this is well known to those to whom it is well known'.

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