would maintain themselves and move further from equilibrium under an energy flux by mutually catalyzing one another's formation without the need for an accurate copying system.

De Duve has performed a valuable service in summarizing existing knowledge concerning the origin of life, and offering suggestions that will provoke thought and debate. The controversies in the field cannot be settled, however, by the publication of books and essays. Experimental results are needed, and the idea of self-sustaining metabolic cycles seems open to laboratory testing and study. The author has described possible ingredients in some detail. If this book inspires some ambitious investigator to devise a system in which a chemical mixture, under a suitable flow of energy, moves away from equilibrium in the direction of greater organization, then its contribution to the field will have been great indeed!—*Robert Shapiro, Chemistry, New York University*

The Discovery and Rediscovery of Mathematical Genius

The Man Who Knew Infinity: A Life of the Genius Ramanujan. Robert Kanigel. 438 pp. Charles Scribner's, 1991. $27.95.

The life story of Srinivasa Ramanujan (1887–1920), the legendary mathematician from India, is astonishing in many ways. Without any formal training he produced results of incredible depth and beauty that challenged some of the finest minds in England during the beginning of this century. What is even more remarkable is that he discovered many of these results while in South India, where the traditional Hindu way of life had changed little over the centuries. Professor G. H. Hardy of Cambridge University was immensely impressed by these discoveries and arranged for Ramanujan to go to England. Although Ramanujan had great difficulties in adjusting to the British way of life, he wrote several fundamental papers in Cambridge. But the rigors of life in England during World War I, combined with his own peculiar habits, led to a rapid decline in his health. This forced him to return to India, where he died a year later.

Even from his deathbed Ramanujan made startling discoveries on mock theta functions, about which I shall comment later. During his all-too-brief life of 32 years, he left numerous results that were unique in their beauty, deep, fundamental and of lasting value; together they place him among the greatest mathematicians in history. Hardy published 12 elegant lectures in 1940 explaining many facets of Ramanujan's work; in the past few decades, the American mathematicians George Andrews, Richard Askey and Bruce Berndt have published several books and monographs expanding on Ramanujan's ideas. But this is the first detailed biography of Ramanujan, and Robert Kanigel is successful in bringing out Ramanujan's drama in a most interesting manner.

Ramanujan was born on December 22, 1887, in an orthodox South Indian Brahmin family. His parents, who lived in Kumbakonam, a small town in what is now the state of Tamil Nadu, had been childless for many years. They prayed to the Goddess Namagiri, the deity in the neighboring town of Namakkal, to bless them with a child. Promptly Ramanujan's mother became pregnant and gave birth in the nearby town of Erode, her mother's place. To his parents Ramanujan was a divine gift, and the goddess of Namakkal was held in great veneration by his family. Ramanujan grew up in a traditional Hindu environment, learning stories from the great epics and verses from the Hindu holy scriptures.

Ramanujan showed signs of his special mathematical talent early. He kept notebooks in which he would regularly jot down his findings. What was most strange was the manner in which he arrived at his results, and this still remains a mystery. Often, he would suddenly get up in the middle of the night and immediately write down identities involving infinite series and products. Those near him have said that Ramanujan used to mention that the Goddess of Namakkal appeared to him in his dreams and presented him with these incredible formulae. As an agnostic, Ramanujan's British mentor, Hardy, dismissed the story of the goddess as mere fable. That such divine inspiration is often considered to be the cause of work of exceptionally high quality, however, is more acceptable to a Hindu than to someone steeped in Western tradition. For instance, Hindus believe that it was the blessing of Goddess Kali that instantly transformed Kalidasa from a shepherd to a poet par excellence!

During his school years, Ramanujan's excessive preoccupation with mathematics led to his neglect of other subjects, and he had to drop out of college. In 1909, With the intention of making him more responsible, Ramanujan's mother arranged to have him married to Janaki, who was then only a nine-year-old girl.

Next, Kanigel describes Ramanujan's efforts in approaching influential people for financial assistance so that he could pursue his research unhindered by the distractions of a job. What Ramanujan really needed was the attention of a leading mathematician. India was a British colony, and so it was natural for him to write letters to British professors stating his results. And it was Hardy who responded favorably.

G. H. Hardy was, at the beginning of this century, leading the revival of British mathematics, which had taken a back seat in the post-Newtonian era. Because he was well known, Hardy was used to receiving letters from amateur mathematicians who made false claims about the solutions of famous problems. So in January, 1913, when a letter from Ramanujan arrived containing a long list of formulae without any proofs, Hardy's first reaction was to ignore the letter as one written by a fraud. However, a closer look showed that there were several beautiful formulae, some of which defeated him completely. Hardy came to the conclusion that it was more probable that Ramanujan was a genius, because a fraud would not have had the imagination to invent such identities! A correspondence followed, and Hardy invited Ramanujan to Cambridge so that his raw, untutored genius could be given a sense of direction.

Both Ramanujan's reaction to this invitation and his mother's were negative. At that time, orthodox Hindus believed that it was sinful to cross the seas. Once again the Goddess of Namakkal provided the solution! This time his mother had a dream in which she saw Ramanujan being honored in an assembly of European mathematicians, and the goddess instructed her not to stand in the way of her son's recognition. So, finally, Ramanujan sailed for England in 1914. Ramanujan's reluctance to go to England without his mother's permission was a typical Hindu reaction. It is a common practice in India, even today, to seek the blessings of elders before embarking on a voyage.

During his few years in England, the rise of Ramanujan's reputation was meteoric. In each of his frequent discussions with Hardy, he showed several new results. For example, under Ramanujan's magical hand, the theory of partitions that had been founded by Euler underwent a glorious transformation. Ramanujan discovered several astonishing new theorems on partitions involving congruences and continued fractions. In collaboration with Hardy, he showed how to obtain an accurate formula for the number of partitions of an integer. This is the famous circle method so widely used in number theory today. In another paper with Hardy, he began the investigation of round numbers that led to the creation of probabilistic number theory several years later by mathematicians such as Paul Erdos. His research was so impressive that he was elected a Fellow of The Royal Society (F.R.S.) in 1918.

Ramanujan, who was a gregarious and

orthodox Brahmin, found himself in an awkward position amid educated Englishmen who were aloof. Socially, Hardy was the opposite of Ramanujan. This book is a dual biography, of Ramanujan and Hardy, and Kanigel succeeds wonderfully in showing the gulf that separated the two. What bridged this gap was mathematics, but here too they differed considerably in the way they thought. Ramanujan was a genius who conjectured and made giant leaps of imagination; as a seasoned mathematician, Hardy put emphasis on rigor and proceeded by logical step-by-step reasoning.

England's climate proved disastrous for Ramanujan's health. He never adjusted to the cold weather. He was in and out of sanatoriums, being treated mainly for tuberculosis. Having been used to the curries and spices of India, he found English food to be tasteless. In 1919 his health became so bad that he returned to India. He died the following April in Madras.

Hardy felt that the real tragedy was not Ramanujan's early death, but the fact that he had wasted much time in India rediscovering past work. He argued that the best creative work is done when one is very young and, therefore, that at the time of his death, Ramanujan was perhaps already past his prime. But here Hardy may have been wrong. Ramanujan's now-famous work on the mock theta functions was done during his last few months in India. He wrote one last letter to Hardy summarizing his discoveries. They are now considered to be among his deepest contributions. Ramanujan was definitely on the rise, and he could have reached even greater heights had he lived longer.

Hardy compared Ramanujan to Euler and Jacobi as a genius. Yet he was of the opinion that Ramanujan's work was strange, and that it lacked the simplicity of the very greatest works. With recent advances in the theory of modular forms and the research of Andrews on Ramanujan's "Lost Notebook," we now realize that Ramanujan's work is more fundamental than Hardy had ever imagined. Ramanujan's equations are now being used to compute *pi* (the ratio of the circumference of a circle to its diameter) to a billion digits! Atle Selberg of the Institute for Advanced Study at Princeton has said that it will take many more decades, possibly more than a century, to fully understand Ramanujan's contributions.

The fascinating story of the discovery of the "Lost Notebook" is described in this book. Shortly after Ramanujan's death, his widow, Janaki, collected all the loose sheets on which Ramanujan had scribbled mathematics and sent them to Hardy. They contained more than 600 formulae, including many on mock theta functions. Hardy handed this manuscript to G. N. Watson, who wrote two papers on this topic. After Watson's death this manuscript was placed along with Watson's papers at the Wren library in Cambridge University, and the mathematical world remained unaware of its significance. In 1976, however, Andrews stumbled across the manuscript while doing some reference work at Cambridge University. He recognized it instantly as a priceless treasure and has been analyzing its contents ever since.

When Ramanujan's centenary was celebrated in India in December 1987, mathematicians from all over the world came to pay homage to this legendary genius. There were several conferences held in India, of which two were in Madras. The first of these was at Anna University, for which Andrews had come in connection with a session on number theory that I organized. Mrs. Ramanujan, who was 87 years old, was present on the opening day. Kanigel says "Andrews, his voice choked with emotion, presented Janaki with a shawl. It was she who deserved the credit for the Lost Notebook, he said, since it was she who kept it together while Ramanujan lay dying." At the second conference, India's prime minister, Rajiv Gandhi, presented two copies of the "Lost Notebook," the first one to Mrs. Ramanujan and the other to George Andrews.

Bruce Berndt is editing the notebooks of Ramanujan. He has published three volumes, and two more are forthcoming. Andrews and Berndt have plans to edit the "Lost Notebook." Owing to the efforts of Andrews, Askey and Berndt, it is now possible to include Ramanujan's work as part of the regular graduate mathematics curriculum. And, by reading this fascinating biography, students will be drawn to a study of Ramanujan's spectacular results.—*Krishnaswami Alladi, Mathematics, University of Florida, Gainesville*

The Interactive Character of Nature and Society

The Earth as Transformed by Human Action: Global and Regional Changes in the Biosphere Over the Past 300 Years. B. L. Turner II, William C. Clark, Robert W. Kates, John F. Richards, Jessica T. Mathews, William B. Meyer, eds. xvi and 713 pp. Cambridge University Press with Clark University, 1990. $100.

In the year 1864, as the Civil War was winding down, an American statesman-scholar named George Perkins Marsh (1801–1882) published a seminal study entitled *Man and Nature: Or Physical Geography as Modified by Human Action*. It is considered by many to be the work that marks the beginning of an awareness of human impingement on our supporting terrestrial ecosystem. Marsh's concern for this accumulating human intervention had been stimulated by his observations during several years of residence in the worn lands around the Mediterranean. Nearly a century later, in 1955, the Wenner-Gren Foundation sponsored an international symposium at Princeton on "Man's Role in Changing the Face of the Earth." Dubbed a "Marsh Festival," it elaborated and updated some of the themes originally laid out by the perceptive Vermonter. The results, some 54 papers and extensive accompanying discussions, were published the following year in a weighty and influential volume edited by William L. Thomas, Jr.

Now comes another ambitious stocktaking and analysis of the societal-environment relationship, this time within a temporal frame of 300 years. It is the product of a major international symposium at Worcester, Massachusetts, in the fall of 1987, instigated and organized under the sponsorship of Clark University and supported by not one but eight foundations. Forty-two papers, mostly multiauthored contributions prepared for the conference, with additional introductions and connecting commentaries, have been brought together and handsomely edited by a steering committee headed by geographer B. L. Turner II.

This symposium was notable both for its comprehensiveness and for the range and authority of its nearly 100 participants from both the biophysical and social sciences. It responded to the increasingly polarized and often contradictory judgments of optimists ("cornucopians") on one side and pessimists ("Cassandras") on the other regarding the future of the earth as human habitat, and the prospects for maintaining its livability and productivity. It was conceived and organized by present and former members of the Clark School of Geography, including Robert Kates, now of Brown University, and Leonard Berry, now at Florida Atlantic University.

From the outset, the organizers envisioned the symposium as a lineal descent from Marsh's *Man in Nature* and the more recent Princeton meeting. The contributions in this volume are substantially more technical, better documented, and more specifically focused than those of its predecessor, *Man's Role*. At the Clark conference "transformation" was the operative word—perhaps a harsher, more decisive term than the "modification" generally