ing as well as the challenges and opportunities faced by lighting designers working in a rapidly evolving marketplace. Author Nisa Khan's concise and unique perspective brings together key issues related to both the evolution and practice of next-generation lighting.

Khan, an independent R&D consultant, has an extensive background in solid-state lighting technology. She also has a profound understanding of the SSL industry and the technology's commercial applications. Her impressive research experience includes work at Bell Labs followed by a career that focused on solid-state technology development.

Understanding LED Illumination begins with a concise introduction to lighting metrics and design. It quickly introduces the technologies involved and the basic science behind LED lighting, and it offers a brief analysis of the current and future prospects of the LED industry. After that, it progresses nicely into devices and the materials and production issues associated with them. Khan then weaves that information into applications, introducing lighting design and the process of moving from conventional or "legacy" lighting to SSL.

Lighting designers and engineers will find the significant amount of material on measurements and related processes quite useful. The author includes a detailed discussion of LED photometrics, including the color rendering index (CRI) and other established standards for measuring color characteristics; with the advent of SSL, that topic is one of current industry debate. I was particularly impressed with the author's ability to explain some of the nuances of LED technology in a straightforward manner that will be easily understood by those newly acquainted with the industry.

Understanding LED Illumination would make an excellent textbook for teaching illumination engineering, architectural engineering, and other subjects related to next-generation lighting. The monograph is extremely well organized and its tables, charts, diagrams, and photographs effectively reinforce the concepts described by the text. It can also serve as a ready reference for those involved in the design, engineering, and marketing of SSL. I recommend it to anyone interested in SSL lighting, including, in particular, my lighting design students and the industry partners I work with as director of the California Lighting Technology Center at the University of California, Davis. I also commend the book to the fast-growing cadre of technicians and engineers entering the SSL marketplace. Many of them are coming from peripheral or distant fields and could use this type of concise yet technically rich material.

I have only a couple of criticisms for Khan's otherwise excellent work. I would have liked to see the illustrations complemented by case studies of actual lighting retrofits or installations for various applications. I also would have liked to see more of the photos and diagrams enhanced with color, particularly given the subject material. The investment in more colorful graphics would be returned with an even more broadly appealing book.

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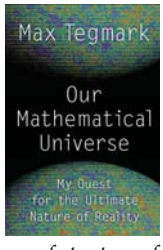
Our Mathematical Universe

My Quest for the Ultimate Nature of Reality

Max Tegmark
Knopf, 2014. $30.00 (432 pp.).
ISBN 978-0-307-59980-3

Theoretical physicist Max Tegmark's *Our Mathematical Universe: My Quest for the Ultimate Nature of Reality* is sometimes delightful but often annoying, sometimes fascinating but other times frustrating.

The author does present an engaging and informative overview of some profound aspects of cosmology—in particular, as they pertain to the origin and evolution of the universe. The figures are extremely well done and informative. I don't think I have seen inflation explained more clearly for a general audience.



The presentation is informal and sometimes charming. But Tegmark, a professor at MIT, can be a little overdramatic, and he takes many side trips to relate stories of his life and career. It's a matter of taste, of course, but after a while I found those two features distracting. A shorter, more straightforward book might not have been a bad thing.

Tegmark writes that the purpose of his book is to convince readers that the universe is a mathematical construct. To be clear, he is not merely discussing the use of mathematics in modeling physical phenomena, nor is he speculating about the "unreasonable effectiveness"

of mathematics when applied to physical problems. Rather, he is arguing that the physical universe is itself an aspect of mathematics. I'm far from certain how one would construct a convincing argument for such a claim, but in my opinion, *Our Mathematical Universe* doesn't pull it off.

The main problem, I believe, is that the book's argument is circular. Tegmark assumes that mathematical objects defined by mathematical axioms—for instance, the real numbers and Lebesgue measure—are part of physical reality. Given that the abstract notions of real numbers and measure have the same status as, say, observations of the spectral lines of sodium, it is not too surprising to end up thinking that the universe is part of mathematics.

On occasion, Tegmark's assertion of the physical reality of mathematical constructs leads to difficulties. One example comes up in his discussion of the many-worlds interpretation of quantum mechanics. In that picture, observations that would give a random yes or no result in the usual Copenhagen interpretation instead give rise to two worlds, one having yes as the result and one having no.

The worrisome argument involves mathematician Émile Borel's notion of normal numbers—numbers that in some rigorous sense could be regarded as random. Borel proved that except for a set of "zero size" (zero Lebesgue measure for the experts), all real numbers are normal. Tegmark invokes that theorem to explain why we never encounter a world in which yes or no experiments that are supposed to give random-seeming results actually give results that look nonrandom. He mentions none of the rigorous mathematics involved in Borel's demonstration, but instead dramatically exclaims that Borel confronted mathematicians "with a theorem at the heart of classical mathematics that could be reinterpreted in terms of probabilities even though the theorem itself never mentioned probabilities at all." In fact, the word *probabilités* is in the title of Borel's paper.

In any case, the real issue is that Tegmark regards the theorem as a result about physics. That's problematic because although the normal numbers make up almost everything, almost none of them are known explicitly. Never mind that you can only run a finite number of experiments; given an infinite string of random-seeming physical results expressed as a binary sequence of 1 (yes) and 0 (no), you can't determine if it actually represents a normal number, as the Borel theorem would predict.

But perhaps the most important question about Tegmark's claim is, Does it matter, except perhaps to those interested in metaphysics? Most of his assertions can't be tested, and whether you accept them as true or not seems to make no difference to the future development of physics.

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