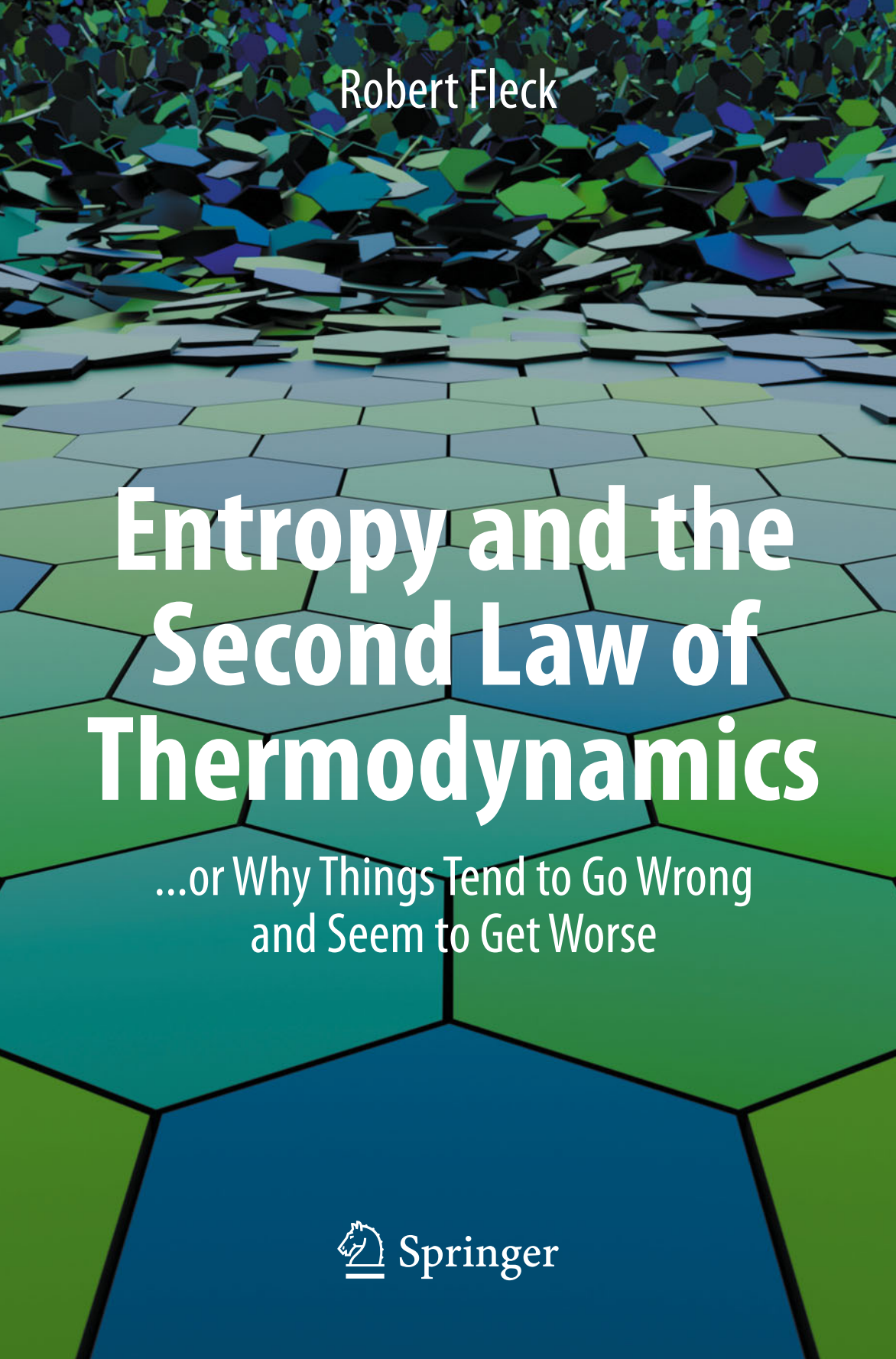
Robert Fleck
Entropy and the Second Law of Thermodynamics
...or Why Things Tend to Go Wrong and Seem to Get Worse
Springer

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Considering the myriad ways in which energy regulates our lives, the laws of thermodynamics assume a dominant role that overshadows the significance of human laws.

—Hans Christian von Baeyer, *Warmth Disperses and Time Passes: The History of Heat* (p. 18)

…the world is getting worse… If the direction of the universe is towards degradation, what room is there in it for the emergence of exquisite structures, of people, and of noble thoughts and deeds?... How could the increasing mastery of matter be compatible with a future of the universe that was drifting inexorably towards a Hogarthian gutter?

—Oxford chemist Peter Atkins, *Galileo's Finger: The Ten Great Ideas of Science* (p. 124)

Closed systems inexorably become less structured, less organized, less able to accomplish interesting and useful outcomes, until they slide into an equilibrium of gray, tepid, homogeneous monotony and stay there.

—Harvard psychologist Steven Pinker, "The Second Law of Thermodynamics" (p. 17)

With the law of entropy, discovered by Rudolf Clausius, it became known that the spontaneous processes of nature are always related to a diminution of the free and utilizable energy, which in a closed material system must finally lead to a cessation of the processes on the macroscopic scale.

—Encyclical address given by Pope Pius XII to the Pontifical Academy of Sciences (1951)

And so castles made of sand/Fall in the sea eventually.

—American musician Jimi Hendrix, *Castles Made of Sand* (1967)

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I thank a lifetime of students—so many of them—for working with me to understand the science of thermodynamics, so important in so many ways,

especially now in today's warming world—and for all their questions that over the years have given me, in turn, a much better understanding of the subject. It has been a pleasure and a privilege to have spent a lifetime in the classroom with all of them, and it is to them that I dedicate this book.

… on the beach in Daytona Robert Fleck
April 2023

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About the Author

Robert Fleck is Emeritus Professor of Physics and Astronomy in the Department of Physical Sciences at Embry-Riddle Aeronautical University in Daytona Beach, Florida, where for four decades he developed and taught a large number and a wide variety of undergraduate and graduate courses in physics, astronomy, general science, and history of science. For inspiring his students with his passion and enthusiasm for teaching and lifelong learning, he received the University Outstanding Teaching Award in 2000 and 2015, as well as over a dozen faculty appreciation awards from graduating senior classes. Professor Fleck is a NASA and National Science Foundation supported star and planet formation theorist; he has published in a wide variety of disciplines, including physics and astronomy and the history of science, and he has been a Visiting Scientist at the National Radio Astronomy Observatory and a Perren Visiting Fellow at the University of London. He also pioneered Embry-Riddle's study abroad program, teaching classes in England, France, Italy, and Greece, and he has recently completed a book-length manuscript titled *The Evolution of Scientific Thought: A Cultural History of Western Science from the Paleolithic to the Present*. When not reading or writing, he enjoys swimming, surfing, cycling, and traveling.

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Introduction

Summary Of all the exemplars the English scientist and novelist C. P. Snow could have used over half a century ago to delineate the two-culture, science-humanities divide, he chose the Second Law of Thermodynamics and Shakespeare, each one a powerful ambassador for their respective "cultures." This introductory chapter summarizes the book's purpose to help the reader understand, with a minimum of mathematics, Entropy and the Second Law of Thermodynamics, nature's Murphy's Law describing the perceived perversity of a universe where it's easy for things to go wrong—and to get worse—easier to make a mess than to clean it up. It is hoped that the reader will then feel more at home on the science side of Snow's cultural divide and hopefully more comfortable in a universe that is nevertheless inexorably running down and out. Although there's much more to science than the Second Law of Thermodynamics, very few laws of nature have had such wide-ranging implications for the workings of our world: indeed, it has been called "the most important and fundamental idea in the whole of science." Even Shakespeare understood that the world "wears, sir, as it grows."

Anything that can go wrong will go wrong.
—attributed to aerospace engineer Edward A. Murphy Jr. (1949)

As a child of the universe, and as a teacher of physics, I had to write this book. It's not a happy book. In fact, it's quite depressing, almost guaranteed

R. Fleck, *Entropy and the Second Law of Thermodynamics*,
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to bring you down. But that's nature. Nothing we can do about it. Just have to live with it.

I used to think I was just unlucky in life. Until I studied physics and learned about the Second Law of Thermodynamics. It's a law of nature. One of those invariable patterns of behavior occurring with unvarying uniformity in nature. Not my favorite, but, again, nothing I—or anyone—can do about it. I'm not a pessimist and I didn't write this book to bum you out. As a scientist (I'm an astrophysicist, a star and planet formation theorist) I'm a realist; as an educator I'm an idealist (a necessary prerequisite, especially in these times); and, despite nature, I'm a mild optimist (even if things don't always seem to work out for the best). I wrote this book to help you understand why things often have a tendency to go wrong and sometimes seem to be getting worse, why it's tough just to break even, let alone get ahead. I want you to know that none of this downward spiral in nature is your fault; it's just nature. And I want you to appreciate that much of the anxiety over the Second Law—over living in a universe that is continually running down and out—stems from our early-modern conception of nature imagined to be quite separate from ourselves, a nature to be controlled rather than understood. I hope that by learning about all this, you'll be better prepared to deal with it all. And, believe me, we have to deal with it. We have no choice in the matter. It's a law of nature. After you understand all of this, maybe even you, too, will find a place for optimism in the midst of all this madness. I hope so. The world needs more of that, for sure.

And by understanding the Second Law of Thermodynamics you'll be part of at least one of the "two cultures" the English physicist and novelist C. P. Snow described in his influential 1959 Rede Lecture, published the same year in book form as *The Two Cultures and the Scientific Revolution*. His thesis was that science and the humanities (this latter represented by "literary intellectuals"), which together embody "the intellectual life of the whole of western society," had split culture into two dangerously noncommunicative, non-overlapping, mutually incomprehensible camps, and that this division was a major impediment to a proper functioning society. He blamed this great divide on the British education system—specifically, on the overspecialization of the educated elite—for emphasizing the humanities over the sciences, despite the importance of the latter in our modern scientific world. Here is what he said [1, pp. 14–15]:

> A good many times I have been present at gatherings of people who, by the standards of the traditional culture, are thought highly educated and who have with considerable gusto been expressing their incredulity at the illiteracy of scientists. Once or twice I have been provoked and have asked the company