Preface

This book is a sequel to my previous book, *Entropy Demystified*, which was published in 2007. While writing that book, I had in mind the layperson as my target audience. I presumed that the potential reader need not have any background in science and all that was required to understand that book was plain common sense and a willingness to use it.

From the feedback I got from both scientists and non-scientists, it became clear to me that I was wrong. One reader of the book, who is not a scientist but has a PhD in musicology, told me it was too difficult to understand. I asked her why. After all, I wrote it for the layperson. Her answer was: "You are right, the book *is* written for the layperson, but I am not even a layperson".

With this and similar comments I have received, I decided that I must bring down the level of the book even further. In a sense, this book could be viewed as a prequel to my previous book. I have done my utmost to translate relatively difficult and highly mathematical concepts into a simple, clear, and familiar language. I hope I have succeeded in doing that.

This book was planned quite differently from the previous one. It is addressed to anyone who is curious about the world around them and is willing either to perform or to follow some simple experiments with marbles distributed in boxes or cells. There is no need to know any mathematics to be able to understand the contents of this book.

In Chapter 2 of my previous book, I discussed in detail two of the central concepts underpinning the Second Law of Thermodynamics: probability and information.

In the present book, however, I refrain from doing that. Instead, I have based the entire book on what you, the reader, already know of these two central concepts.

Many who have read my previous book have commented that there are too many footnotes in the text, which distract the attention of the reader. I have therefore done away with footnotes in this book and have instead moved them to a separate chapter (Chapter 8), where some technical issues are discussed very briefly. Now the reader can read and hopefully understand the book without any interruptions.

Notwithstanding the lack of distracting notes, I have deliberately strewn within the pages of this book some distractive materials that I refer to as "snacks". Some of these "snacks" are simple, entertaining stories, some others are "brainteasers," but all are meant to ease your way through the book and make the reading experience more enjoyable.

Understanding a scientific book, even at the most elementary level, requires *active reading*. This is especially true when you are expected to follow experiments, analyze results, search for regularities or irregularities, recognize patterns that are common to all the experiments, and hopefully discover something new.

Active reading may also be beneficial to your health. As you might know, until recently it was believed that we are born with a fixed number of neurons in our brains. As we age, many neurons fade out and die, resulting in the reduction of brain function. However, it has now been discovered that new neurons are born even after childhood. These new neurons are short-lived and, unless you use them, you lose them!

It is therefore to your advantage and benefit to read the book *actively*, as this will maintain your mental capabilities. To work through a chapter a day might well keep Dr Alzheimer away!

There is another health-related benefit of these entertaining "snacks." It is a well documented fact that a smile or a laugh can significantly boost your immune system: I hope some of these "snacks" will elicit a healthy smile.

An effective way to read this book actively is to take a break, have a "snack", and try to repeat an argument or re-derive a conclusion by yourself. It is not uncommon for a student to believe that he or she understands an argument when in fact there is only a delusion of understanding. In my experience, I have found that the best criterion I can apply to test my understanding of what I have read is to explain it to someone else. Entropy and the Second Law are quite tricky to understand. If you only scan along the lines of the book you might fall into the trap of having a false sense of understanding what you have read. For this reason, you should be engaged in active reading and test your understanding by trying to explain what you have read to someone else.

The structure of this book is as follows.

Chapter 1 provides a very brief introduction to the Second Law of Thermodynamics. This chapter is not meant to *teach* you the Second Law. You will have to discover it yourself.

Chapter 2 presents two central concepts: probability and information. Again, this chapter is not meant to *teach* you either probability or information. Instead, it is meant to show that you already know what you need to know for understanding the Second Law. I hope that this chapter will convince you that you can understand the entire book.

In Section 2.2, we shall see that children as young as 6–9 years old already have an intuitive understanding of the concept of probability, even though they cannot define this concept.

Section 2.3 is devoted to the concept of information and its measure. I presume that everyone knows what "information" is, although it is very difficult to define. However, in this chapter we shall not discuss "information" itself but some measure of the *size* of information.

In fact, we shall zero-in on a specific, more limited, and more precise concept of Shannon's measure of information (*SMI*), which can also be grasped easily by children who have played the popular "20-questions" (20Q) game. At quite an early stage, children intuitively feel that certain strategies of asking questions are more efficient than others; that is, efficient in the sense of asking the minimum number of questions to obtain the required information. It is here that Shannon's measure of information is introduced, not mathematically and not formally, but indirectly through the more familiar 20Q game.

Within Chapters 3–5 lies the core of the book. Here, we shall carry out various experiments with marbles in cells. The experiments were designed in such a way that you will not get bogged down in numerous, fruitless trial and error cases.

Although I am not going to teach you the Second Law, I will help you with the methodology of the scientific work. I presume you have heard of Charles Darwin. During his long and extensive trips around the world, Darwin *collected* and *registered* a huge number of lifeless and seemingly unrelated items. Those items would have remained lifeless forever had Darwin not penetrated into the significance of these items and discovered how the diversity of living creatures has emerged from the lifeless and seemingly unrelated items.

While learning the methodology of the scientific work, we shall make some important discoveries. In Chapter 3, we shall discover the *uniform distribution* and how it is related to the Second Law. In Chapters 4 and 5, we shall discover the Boltzmann distribution and the Maxwell–Boltzmann distribution, and how they are related to the Second Law.

In Chapter 6, we shall summarize all that we have learned from the experiments described in Chapters 3–5. We shall formulate the Second Law for the system of marbles in cells. In a nutshell, we shall first define the "size" of the games played in Chapters 3–5. This "size" measures how easy or difficult the game is. This measure will be the analog of the entropy. The Second Law, in game language, states: Every game will always evolve in such a way as to become more difficult to play. This evolution will stop when we reach the equilibrium state, at which point the game becomes most difficult to play.

I believe that these analogs of entropy and the Second Law will be easy to grasp in the world of marbles distributed in boxes or cells. Once you feel comfortable with these concepts in the context of the marbles, there remains only the technical chore of translating from the language of the marbles in cells into the language of real particles in real boxes. As a result of this translation, the concepts of entropy and the Second Law in will be ripe for the picking.

Chapter 7 is a translation of Chapter 6, from the language of marbles in cells to the language of real systems of particles in boxes. In this chapter we shall discuss the three central questions relevant to the Second Law: What is entropy? Why does it change in one direction only? How does the system evolve from any arbitrary initial state to the eventual equilibrium state? You will also learn the workings of the Second Law in phenomena that you encounter in your day-to-day life.

You certainly know that if you spray even just a small amount of perfume in the corner of a room, you will notice that after a few minutes it will expand and occupy the entire room. But did you also know that the spread of the perfume molecules in the entire room will be *uniform*? This is not a trivial matter to prove, as we shall discover in Chapter 3. What about the distribution of the same drop of perfume in a column of air that extends vertically towards the sky? This is not a trivial question either. The distribution will be far from uniform. Thanks to Boltzmann, pilots could measure their altitude *without* sending any signal to the earth. If you cannot appreciate this achievement, think about measuring the distance between yourself and any object at some distance from you. Can you measure the distance without sending something to that object? You cannot. You will either have to go there, send someone there, or send a beam of light and measure the time it takes to come back.

Returning to the same drop of perfume, did you ever ask yourself *how* the molecules managed to fill the entire space, considering that they were initially concentrated in one corner of the room? You might have heard that molecules are in constant motion and that this motion "drives" the molecule to reach every accessible point in the room. You might even know that when the temperature is higher, the spreading of the perfume throughout the room will be faster. But do you know the precise distribution of velocities? We shall also become familiar with this distribution in Chapter 5.

Science has evolved in myriads of ways. Scientists use whatever tools are available, either theoretical or experimental, to measure or calculate predetermined quantities. Others may stumble across a new problem and perhaps hit upon a new discovery serendipitously. In most cases, however, a great amount of tedious and routine work, either through experimentation or calculation, is involved before one discovers a new pattern of interest.

In this book I shall try to give you the feeling of, or perhaps the delusion of, discovering a law of nature. In a sense you will use the trial and error method to discover entropy and the Second Law, using a set of experiments that I have designed in order to lead you to that goal along a relatively short path.

Here is my promise to you: If you read the book actively and critically — please send me any errors you find — you will not only boost your immune system, not only keep Dr Alzheimer away, not only *understand* the meaning of entropy and why it behaves in such a peculiar way, but you will also learn about three of the most important probability distributions in science. You will see how these distributions spawned from Shannon's three theorems. These theorems are highly mathematical, yet you will discover them through experimentation with simple games. And above all, you will experience the joy of discovering one of the most mysterious concepts in physics.

This book is dedicated to Claude Shannon. It is well known that Shannon did not contribute anything to thermodynamics or to statistical mechanics. However, this book is not *about* thermodynamics but about understanding entropy and the Second Law. Shannon's measure of information (which we shall use throughout the book) has provided us with a beautiful and a powerful tool to penetrate into the origin of various molecular distributions underpinning the concept of entropy and of the Second Law of Thermodynamics. Shannon's measure of information has transformed entropy from a vague, confusing, and very often mysterious quantity, into a precise, objective, familiar, and crystal-clear concept. Although it was not Shannon's intention to create a tool for understanding thermodynamics, I feel it is fit to pay tribute to Shannon's extraordinary tool, which has been found so useful in so many diverse fields of research.

If you are pondering on the question of whether you can read and understand this book, let me suggest a simple test. On the next page you will find a self-testing kit. It is designed to check your competence in understanding the contents of this book. The first checks your sense of probabilities. The second will tell you if you know how to group objects into "groups of equivalence," and if you are smart enough to play the 20Q game successfully.

I am confident that if you can *read* this test, then you can also pass the test, and are therefore able to read this book.

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