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CHAPTER ONE

PLAYING THE GAME

> Dear Roger,
>
> (XXX) and I have been exchanging letters for some time. As a fan, he's strange; he likes the science better than the fiction. Wants me to quit futzing with the plot and characters and get on with the strange environments. He plays The Game: finds the holes in the science and writes in. I like him. . . .
>
> —LETTER FROM LARRY NIVEN TO ROGER ZELAZNY, JANUARY 3, 1974

1.1 THE PURPOSE OF THE BOOK

When I was young, back in the 1970s and 80s, I read a lot of science fiction. I read a lot of other stuff, as well, but science fiction (and fantasy) filled a need that other literature simply didn't. I tended to read "hard" science fiction, that is, stories plotted around hard science: physics, astrophysics, giant engineering projects, and the like. The worlds these stories portrayed, where space travel was common, human problems such as poverty were nearly eliminated, and conflicts centered on larger-than-life issues, always seemed to me more compelling than

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human dramas that revolved around why someone didn't love someone else.

My tastes have changed since then, but the initial thrill of these stories has never really left me. I am a scientist because of my initial love of these tales. A chill still runs down my spine whenever I look at a Hubble Telescope photo or learn of a new exoplanet discovered. I live in hope that I will be alive when life on other planets is discovered. I still want to take a vacation to the Moon or to an orbiting satellite. These thrills are tempered by my adult realization that much of what goes into science fiction is quite unrealistic. This book is written for my fifteen-year-old self, and other readers like him, who would like to know which parts of science fiction are based on real science, and therefore in some way plausible, and which parts are unrealistic. This is the book I would have wanted to read when I was young. Just as for Niven's correspondent, my interest in science fiction was mostly in the strange environments, the new worlds, the alien life, the superscience it portrayed. I wanted to know which parts were (potentially) real and which weren't. To a large extent, that is why I eventually became a physicist.

Almost any science fiction story has a lot of incorrect science. This doesn't make the story bad or invalid. Some authors, like Larry Niven, are almost obsessive in trying to get the science right; most are more lackadaisical about it. However, the standards for the profession are pretty high: no science fiction writer can be really esteemed accomplished unless he or she has a thorough knowledge of basic physics, chemistry, biology, astrophysics, history (ancient and modern), sociology, and military tactics; and besides all this, must possess a certain something in their air and manner of writing, or their profession will be but half-deserved. (Improvement of their minds by extensive reading goes without saying.) Science fiction writers do not have the same opportunities as research scientists do to stay up-to-date in their research fields, and writing science fiction involves a lot more fields than most research scientists can keep up with.

This book is one physicist's attempt to discuss the science, particularly the physics and mathematics, that goes into writing hard science fiction. As an added bonus, I also take a look at physics in fantasy writing: there's more in it than meets the eye. This is not an attempt to predict the future: as G. K. Chesterton pointed out, most of the fun in predicting the

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future comes from burying the people who attempt to do it [50]. Rather, I stick to the science used in crafting the stories. There are many books dedicated to the literary criticism of science fiction; this book is devoted to its *scientific* critique. As such, my choice of which literature to use is dictated both by my own reading and by the needs of the book. I tend to avoid writers who don't make much use of science in their stories, except occasionally to comment on their errors. I also tend to stick to literature, that is, novels and short stories, although I occasionally comment on science fiction movies or television shows as well.

Many have gone down this path before me, scientists and writers alike (and a few who were both). The preeminent standout among science fiction writers is Poul Anderson, to whom this book is dedicated, for his essays "How to Build a Planet" and "On Thud and Blunder." I read both when I was a teen; this book would not have been written but for his example. Isaac Asimov and Arthur C. Clarke both wrote many essays on science. Larry Niven has written several essays on the scientific aspects of teleportation, time travel, and other science fiction themes. Almost from the beginning of the modern era, scientists have written essays on science fictiony ideas, and I reference them where appropriate. This book is mainly synthetic rather than original, although I think there are a few new things in it, such as the discussion of candlelight in the Harry Potter series in chapter 3.

1.2 THE ASSUMPTIONS I MAKE

David Gerrold has written that science fiction authors by necessity almost always involve bits in their work that defy the laws of science as we know them. He refers to places where this happens as instances of "baloneyum." His advice is that beginning authors limit themselves to only one piece of baloneyum per story, experienced authors perhaps as many as two, and only grandmasters put in three instances [94]. It's a good rule.

In this book I have followed a similarly conservative path. In analyzing science fiction my assumptions are that the laws of physics as we understand them now are pretty much correct. They are *incomplete*;

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we don't know all of them, but the incompleteness doesn't really affect most science fiction stories. In particular, I assume that Newton's laws of motion are good enough to describe things larger than atoms, that Einstein's theory of relativity is correct, and that quantum mechanics is the correct description of nature on the microscopic scale. The one example of baloneyum I indulge in is in the consideration of faster-than-light travel and, equivalently, time travel, which appear to be impossible from almost everything we know about physics—but perhaps not quite.

1.3 ORGANIZATION

There are four large sections of the book. Each of them contains several chapters centered on a given theme. The sections are:

1. "Potter Physics." This first section explores physics as used and abused in fantasy novels and series. I've chosen two examples of "urban fantasy" novels to focus on, the Harry Potter series by J. K. Rowling and the Dresden Files novels by Jim Butcher. The issues here are different from those in the rest of the book, for fantasy, by its very nature, cannot adhere strictly to scientific laws. However, we can ask whether the series are at least internally consistent, and whether the magic used in the series makes sense when in contact with the muggle world.
2. "Space Travel." This is the largest single section, consisting of nine chapters, as befits the subject. Space travel is perhaps *the* theme of science fiction, to the point that it almost defined the genre from the 1930s to the 1980s. One goal of this section is to examine not only the scientific issues involved in space travel but also the economic ones. The big question is, why isn't space travel cheap and common now, as it was certainly foretold to be in almost all of "golden age"[1] science fiction?
3. "Worlds and Aliens." This section consists of four chapters exploring the other major theme of science fiction, the possibility of life on other worlds in our Solar System and elsewhere.
4. "Year Googol." This part explores the potential survival of humanity (or other intelligent species) into the far distant future, along lines laid down originally by the writer Olaf Stapledon and the physicist Freeman Dyson.

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My choice of subject matter, like the organization of the book, is idiosyncratic. The book is a loose collection of essays more than a unified text. I write about those aspects of science fiction and fantasy that most interest me. My hope is that my readers are similarly interested. By necessity, I concentrate on those writers whom I know the best, meaning American and British science fiction writers. Since I know the "golden age," New Wave, and early cyberpunk literature best, this may give the book an antiquated feel. I try to include ample description of these stories so that anyone reading the book can understand the scientific points I am trying to make.

A set of problems has been prepared for instructors intending to use this book as a class text. For space reasons, we have placed these problems, organized by chapter, on a website (press.princeton.edu/titles/10070.html). I've also included solutions and hints for the problems. This book cannot be used to replace a physics textbook, but it could be used in a specialized course.

1.4 THE MATHEMATICS AND PHYSICS YOU NEED

I expect the readers of this book to be able to read and use algebraic equations, and to understand them on some level. I intend the book as a working book for science fiction enthusiasts who have at least a decent knowledge of algebra and know what calculus means.

The equations I introduce don't exist in a vacuum; they are mostly drawn from physics, and represent physical quantities. That is, unlike pure mathematics, there is always some connection with the real (or, at least, science fiction) world that is expressed by them. In most cases I explain the equations in detail but do not derive them from basic principles. This is unlike what happens in most physics courses, where the emphasis is as much on deriving the equations as on using them. Since most of my readers aren't physicists, I will explain how the equations are used and why they make sense. I also want my readers to have a conceptual understanding of calculus. There are only a few places where this will crop up, so it isn't essential, but it is useful to know what is meant when I use the terms "derivative" and "integral."

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Physics is the science central to this book. Appendix 1 at the end of the book reviews Newton's laws of motion, which are central to any understanding of physics. Just as a knowledge of grammar and spelling is needed for reading and writing, a knowledge of Newton's laws is needed for any understanding of physics. Newton's laws describe how things move on the macroscopic scale; that is, they are a good description of things larger than atomic size. However, they are only approximations to the truth. The laws of quantum mechanics are the real way things work. It is characteristic of physics that the underlying laws are difficult to see directly. Why this is so, and why Newton's laws are good approximations to the true fundamental laws of nature, are questions beyond the scope of this book to answer. If readers are interested in this, there are dozens of good books that examine these questions. I strongly recommend two books by Richard Feynman, *The Character of Physical Law* and (for those who have a physics background) *The Feynman Lectures on Physics*, particularly book 2, chapter 20 [81][85].

1.5 ENERGY AND POWER

Energy and power, which is the rate at which energy is converted from one form to another, are the key points to understand for this book. Energy is useful because it is conserved: it can be transformed from one form to another, but not created or destroyed. I use energy conservation, either implicitly or explicitly, in almost every chapter of the book. A few of the forms that energy can take are the following:

- Gravitational potential energy: This is the energy that pairs of objects possess by virtue of the gravitational attraction between the members of the pair. This form of energy is very important for any discussion of space travel.
- Chemical potential energy: This is the energy resulting from the spacing, composition, and shape of chemical bonds within a molecule. Chemical reactions involve changes in these properties, which usually means changes in chemical potential energy. In an exothermic reaction, the chemical potential energy is less after the reaction than before it. Energy is

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"released" during the course of the reaction, usually in the form of heat. An endothermic reaction is the opposite: energy must be added to the reaction to make it proceed.

- Nuclear energy: This is the energy resulting from the structure and composition of the atomic nucleus, the part of the atom containing the protons and neutrons. Transformations of nuclei either require or release energy in the same way that chemical reactions do, except on an energy scale about one million times higher.
- Mass: Mass is a form of energy. The amount of energy equivalent to mass is given by Einstein's famous formula

  $$E = Mc^2, \tag{1.1}$$

  where E is the energy content of mass M and c is a constant, the speed of light (3×10^8 m/s, in metric units). This is the ultimate amount of energy available from any form of mass.
- Kinetic energy: This is the energy of motion. Newton's formula for kinetic energy is

  $$K = \frac{1}{2}Mv^2, \tag{1.2}$$

  where K is the kinetic energy, M is the mass of the object, and v is its speed. This formula doesn't take relativity into account, but it is good enough for speeds less than about 10% the speed of light. If an object slows down, it loses kinetic energy, and this energy must be turned into another form. If it speeds up, energy must be converted from some other form into kinetic energy.
- Heat: Heat is energy resulting from the random motion of the atoms or molecules making up any object. In a gas at room temperature, this is the kinetic energy of the gas molecules as they move every which way, plus the energy resulting from their rotation as they spin about their centers. For solids or liquids, the energy picture is more complicated, but we won't get into that in this book.
- Radiation: Light, in other words. Light carries both energy and force, although the force is almost immeasurable under most circumstances. Most light is invisible to the eye, as it is at wavelengths that the eye is insensitive to.

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In the units most often used in this book, energy is expressed in joules (J). The joule is the unit of energy used in the metric system. To get a feel for what a joule means, take a liter water bottle in your hand. Raise it 10 cm in the air (about 4 inches). You have just increased the potential energy of the water bottle by 1 J.[2] Other units are also used; in particular, the food calorie, or kilocalorie (kcal), will be used in several chapters. The kilocalorie is the amount of energy required to increase the temperature of 1 kg of water by 1°C (Celsius). It is equivalent to 4,190 J. Other units are defined as they come up in the chapter discussions.

Power is the rate at which energy is transformed from one form to another. The unit of power is the watt (W), which is 1 J transformed per second from one form of energy to another form. For example, if we have a 60 W light bulb, 60 J is being transformed *from* the kinetic energy of electrons moving through the tungsten filament in the light bulb *into* radiation, every second.

The different forms of energy and their transformations are the most important things you need to know to read this book. With this brief introduction to the subject, we are ready to start.

NOTES

1. Science fiction readers and critics divide up science fiction of the last century into different subgenres, which typically also follow one another chronologically. For example, the "golden age" covers the period from the end of World War II through the mid-1960s, when authors such as Robert Heinlein, Isaac Asimov, and Arthur Clarke were at the peak of their popularity. The major science fiction themes of this time period are space travel and alien contact. I also refer to the New Wave writers of the 1960s and 1970s, such as Brian Aldiss, and cyberpunk literature from the 1980s and later. Of course, many authors, such as Philip K. Dick, resist easy classification. Fantasy is similarly divided, into "sword and sorcery," "magic realism," and "urban fantasy," among other subgenres. Urban fantasies are very useful for this book because they allow side-by-side comparison of fantasy worlds with the real world in which the laws of physics hold sway.

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2. To be specific, you have increased the potential energy of the pair of objects, the Earth plus the water bottle, by 1 J. Potential energy is always the property of a system, that is, of two objects or more, not of an individual object. However, because the Earth essentially hasn't moved, owing to its high mass, we typically talk about the lighter object of the pair as the one whose potential energy changes. Being specific about this is important only when the masses of the two objects in question are about equal.

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