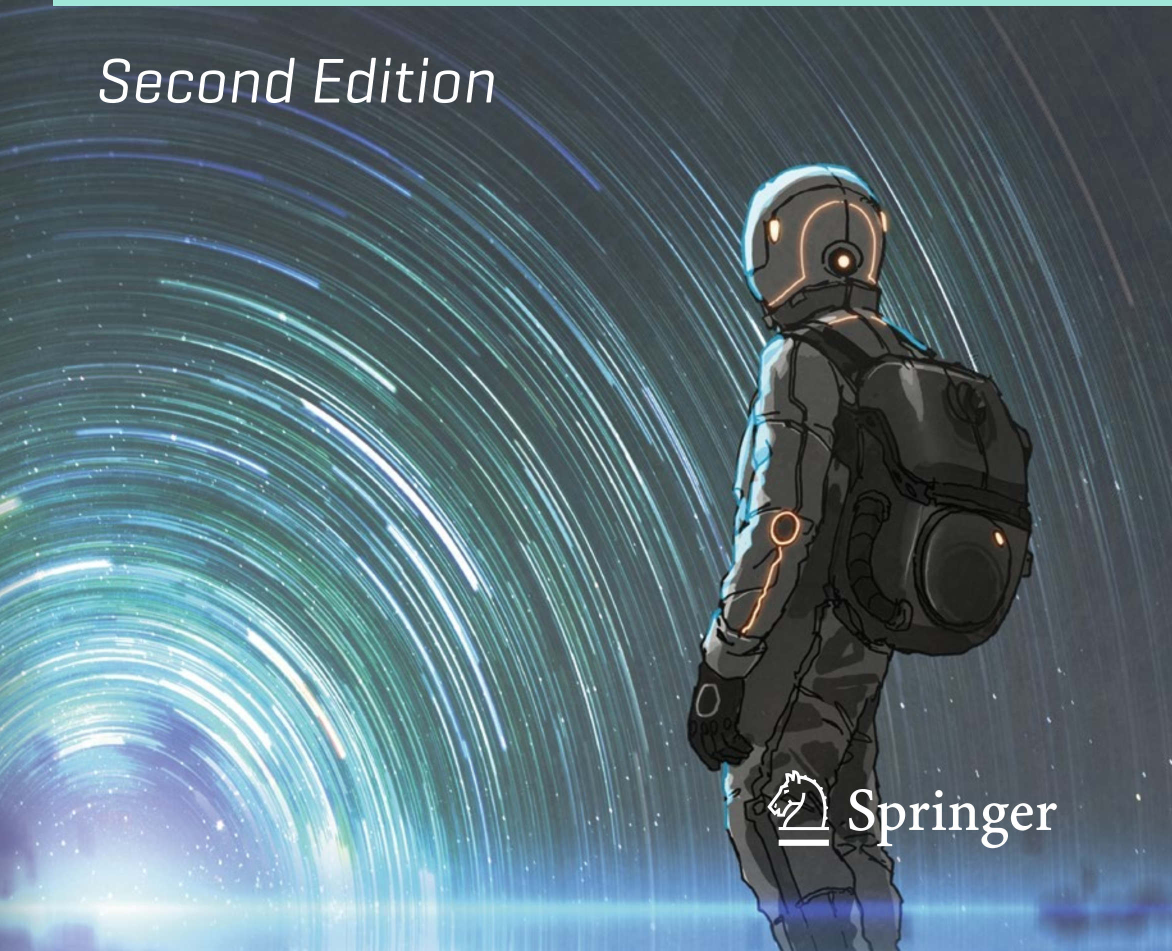
Barry B. Luokkala

Exploring Science Through Science Fiction

Second Edition



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To Janet—my wife, my love, my inspiration

Preface to the First Edition

Science and science fiction have been passions of mine since childhood. But the combination of the two—using science fiction as a vehicle for teaching science—is something that I only began to explore in relatively recent years. We live in an increasingly technological world, in which it is increasingly important for people to be scientifically informed. But traditional courses in science at the college level are usually geared toward students who are already on their way toward careers related to science, technology, engineering, or mathematics—the so-called STEM fields. Although there are some notable exceptions, most of the offerings in science for students in the fine arts, humanities, and social sciences continue to be watered-down versions of courses intended for science or engineering students. Students who take such courses often do so simply to fulfill a degree requirement, and with a sense of trepidation. They often complete such courses with no more interest in science than when they signed up. The present work has one primary goal: to make science accessible to a broad audience, including both nontechnical students, as well as technically oriented students, with a view toward increasing public awareness of science and interest in science.

Content and Scope

The content of the book is organized around seven major questions, which are frequently addressed in works of science fiction: What is the nature of space and time? What is the universe made of? Can a machine ever become conscious? Are we alone in the universe? What does it mean to be human? How do we solve our problems? What lies ahead? There is a deliberate progression in these seven major questions, beginning with the most objective (changing perspectives through history concerning the nature of space and time, the fundamental building blocks of matter, and the properties of materials), followed by topics which have both objective and subjective dimensions (Is consciousness computable? Is there intelligent life elsewhere in the universe? What, if anything, sets humans apart from other closely related species?), and ending with questions that may be more controversial and speculative (How do we distinguish between science and pseudoscience? How is science used or misused in attempts to solve the problems facing society? What will the future hold for our technological society?). In addition to the major questions, each of the chapters includes suggestions for further exploration, with more specific questions and references to scientific literature.

Much of the emphasis in this book reflects my training as a physicist. Yet I do not subscribe to the narrow view of science held by Ernest Rutherford, a famous physicist of the early twentieth century, who proclaimed, “All of science is physics. The rest is stamp-collecting.” A few of my colleagues have an even more narrow view toward science than Rutherford and will tell you that you aren’t even doing physics unless you are doing their particular brand of physics. When it comes to a discussion of what is science, I am willing to embrace considerably more diversity. Yet there are limits. A serious discussion of what is science and what is not science is also included in this book. Not all forms of human inquiry are rightly included under the umbrella of science.

The Approach

Science fiction is used throughout this book as a springboard for discussing both the fundamental principles of science and cutting-edge science research. Short scenes from science fiction movies and television episodes are critiqued in light of our current understanding of science. Class discussion focuses on discerning the level of plausibility of the science depicted in each scene. To this end, four general categories are useful. A handful of examples from some of the best movies turn out to be solidly based on good science—the things that we see on the screen are actually known to happen, essentially as depicted or as described in the dialog. An example that falls into this first category is the relativistic time dilation described in the opening scene of the original (1967) version of the *Planet of the Apes*. The second category includes things which are possible in principle, but beyond our current technology. That is to say, it hasn’t happened yet, but there is nothing in the laws of science to forbid it from happening. An example is the sentient android, Commander Data, in the TV series *Star Trek: The Next Generation*. The third category is stuff that just can’t happen as shown. Much of science fiction may be lots of fun to watch, but is simply impossible, and we will explore the reasons why. An example of this is the extraordinarily rapid rate at which the air leaks out of an interplanetary spaceship, after being punctured by a micrometeoroid, in the 2000 movie *Mission to Mars*. Using a reasonable set of assumptions, we will come up with an estimate of how long it would really take and conclude that the screenwriters simply wanted to heighten the sense of excitement and danger. The fourth category is one that is growing rapidly as our technology advances: things which were purely science fiction at the time that the movie or TV episode was produced, but are now part of reality, or are expected to become part of reality in the very near future. When the movie *GATTACA* was produced in 1997, the Human Genome Project had not yet been completed, and the concept of rapid DNA sequencing, as shown in the movie, was purely in the imagination of the writers. It took the enormous government-funded research project 13 years to complete the sequencing of the first human genome. Full-genome sequencing can now be done in about 1 day at a cost of about $1000.

Plausibility Checks and Quantitative Estimations

Some of the sci-fi illustrations are conducive to doing what we might call a quantitative plausibility check. That is to say, by watching the movie scene we can gather enough information to do a rough calculation, and then decide if what we see could actually happen or not. In the text, I call these *Estimation Problems*. The objective in each case is *not* to obtain a specific answer, which is either right or wrong (the sort of problems encountered in most introductory physics textbooks). Instead, the idea is to come up with an estimate, by making a reasonable set of assumptions to supplement the information you can gather directly from the movie scene. For example, how much power would be required for a handheld weapon, such as a *Star Trek* phaser, to vaporize a human body? The answer that you get will depend on what assumptions you make about how long the vaporization process takes (from watching a relevant scene) and about what the human body is made of. The nontechnical student should not be intimidated by the frequent use of equations in some of the chapters. Where calculations can be done, example problems are worked out in the text, and additional problems are proposed for you to work out on your own. Solutions for these *Estimation Problems* are included in an appendix.

Movie, TV, and YouTube References

Collectively, the chapters include over 180 references to specific scenes in 130 different movies and television episodes, spanning over 100 years of cinematic history. In general, but with a few notable exceptions, I refrain from passing judgment on these works from an artistic perspective. Some of the very worst sci-fi movies ever made actually include some rather useful illustrations and are likely to promote very fruitful discussions in class. Each chapter includes a list of references to movie and TV scenes, in the order that they are cited in the text. The entire collection of movies and TV episodes cited in the text is also included alphabetically in appendices at the end of the book.

Most of the visual material is available on DVD and is referenced by scene number, for ease in selecting the desired scene for a classroom presentation. A few of the scenes from the most recent TV series episodes had not yet been released on DVD at the time of publication, or are not yet part of my personal DVD collection. These are cited by season number, episode number, and air date.

How to Use This Book

The book was created as the primary text for a one-semester undergraduate course on science and science fiction. But anyone with an interest in science and science fiction will enjoy reading it. The level of mathematical sophistication is that of high school algebra, with a small amount of trigonometry. The amount of material included in the book is actually more than can be covered in a single semester. This allows some freedom for the prospective instructor to pick and choose, according to the desired emphasis of the course.

The more casual reader may enjoy looking at a particular science topic to see what sci-fi references are used, or may prefer to look up a particular movie or TV episode in the appendices, to see what science concepts are included. Although the list of sci-fi references is extensive, it's not possible to include every work that was ever produced in a book of this scope. Nevertheless, I hope that there will be something for everyone.

Acknowledgments

The story of the origin of this book is a case study in the orchestration of events. I owe a debt of gratitude to the many individuals and groups of individuals, who have played a role in this orchestration, either knowingly or unawares.

The first of these events happened before I was born, on the campus of what was then known as the Carnegie Institute of Technology. My father enlisted in the army during the Second World War and was stationed at Carnegie Tech, in the Army Specialized Training Program. My mother was working at her first job right out of high school in one of the administrative offices on campus. Neither of them ever imagined when they first met that they would eventually marry and have a son, who would grow up to become a member of the faculty in the physics department, on that same campus, now called Carnegie Mellon University. It's fitting that I should acknowledge my parents. Obviously, without them I would not be here. I am grateful to them for providing the kind of environment in which someone interested in the sciences could thrive and for allowing me the freedom to choose my own path.

The earliest direct influence for the book can be traced back to an event in my seventh grade history class. The teacher, Mr. Joseph Karlik, was also the science and math teacher for seventh and eighth grade at our very small elementary school. He gave us the most unusual assignment for homework one day, which I seem to recall having to persuade my parents to allow me to complete. We had to watch an episode of the new TV series *Star Trek*, called *The City on the Edge of Forever*, which would

air that evening. The episode imagines the possibility of time travel into the past (to Earth in 1930) and the changing of one small event (preventing a traffic accident), which results in all of history unfolding differently (delaying the entry of the United States into the war and allowing Nazi Germany to develop the A-bomb first). The discussion in our next history class focused on how things today might be very different if a significant event of the past never occurred. Although my interest in science fiction had already begun several years earlier, with the cartoon series *The Jetsons*; my real love of science fiction began with this homework assignment. I was intrigued by the possibility of traveling through space and time, and the *Star Trek* character *Mr. Spock* became one of my role models. My other childhood role model was the famous marine biologist Jacques Cousteau. His underwater documentaries, produced by National Geographic, were something that I never missed on TV. Through most of high school, I dreamed of becoming a marine biologist and sailing around the world on the *Calypso* to seek out and study new life forms in the Earth's oceans. I went to college intending to major in biochemistry, which (I hoped) would lead to graduate school in marine biology. But a C in honors college chemistry prompted me to reconsider whether that was the best path for me to pursue. As I pondered which direction I should take, I recalled my high school physics class and Mr. David Speer, who was without a doubt the best teacher I ever had in high school. I credit him, and the very positive experience I had in his classroom and laboratory, with the decision to change my major from biochemistry to physics. Thus began a long and complex path, which eventually led me to the physics department at Carnegie Mellon University.

Although he sometimes questions my sanity for doing things in nontraditional ways, I owe a very big debt of gratitude to Steve Garoff, my PhD thesis advisor and one of my closest colleagues in the physics department. Steve and I began our association in his second semester as a faculty member at Carnegie Mellon, when he was assigned to teach our advanced undergraduate laboratory course. I had already been working in the department for some years as a lecturer, primarily for our introductory lab courses, but had also been assisting regularly with our advanced lab course. Toward the end of the semester, Steve was lamenting to another colleague that he had lots of startup funds, but only one graduate student. I told him that by coincidence, I had been kicking around the idea of finally growing up and pursuing a PhD, and his research was very much of interest to me. The words had hardly left my mouth when Steve invited me to join his research group. My future would certainly have unfolded very differently, if Steve had not provided the opportunity to work with him—a decision, which I'm sure neither of us has ever regretted.

The basic framework for the book began to develop after the convergence of three events in the second half of the 1990s. The first of these events happened late in 1995, thanks to Janet, my one and only wife of more than 30 years now. At the time, she was working at Pinocchio Bookstore for Children, one of the last of a dying breed of independently owned bookstores in Pittsburgh. In this position, she had easy access to information about all the latest books for grownups, as well as for children. Knowing my love of science fiction, in general, and of *Star Trek* in particular, she surprised me one day with a hardcover copy of *The Physics of Star Trek*, by

Lawrence Krauss, which had just been published that year. Delightful to read, this brilliant work holds a permanent place on my list of all-time favorite books.

The second event in this trilogy came in November of 1996, when Lawrence Krauss, author of *The Physics of Star Trek*, visited Carnegie Mellon University to give a lecture, complete with video clips from some of his favorite *Star Trek* episodes. As I sat in the audience, enthralled by his presentation, I started thinking that something like this would make a great course. Following the presentation, I managed to get Krauss to sign my first edition copy of his book, but wondered when I would ever have the time or opportunity to follow through on developing a course on the topic.

Two years later, in the fall of 1998, the opportunity presented itself. Susan Henry, then dean of the Mellon College of Science at Carnegie Mellon (1991–2000), called upon the faculty to create mini-courses, whose primary purpose would be to keep first-year students interested in science. I proposed a course which would use science fiction as a springboard for discussing cutting-edge science research. Although I am a physicist, and my idea for the course was inspired by Lawrence Krauss and *The Physics of Star Trek*, there is much more to science than just physics, and science fiction encompasses much more than just *Star Trek*. I planned a 6-week mini-course around five major topics: the nature of space and time, properties of solid-state materials, robotics and artificial intelligence, the search for extraterrestrial intelligence, and the future of our technological society. Students would watch clips from a broad range of science fiction movies, spanning a century of cinematic history, as well as selected sci-fi television episodes, and critique the science content of the clips in light of our current knowledge. Class discussions would focus on assigned readings from current science literature. The proposal was received with great enthusiasm, and I've been offering the course once or twice every year since the spring of 1999. Special thanks are due to Walter Pilant, whose vast personal collection of episodes of *Star Trek* (both the original series and *The Next Generation*) provided many hours of useful background research and preparation for the course. Thanks also to Jeffrey Hinkelman, my dear friend and manager of Carnegie Mellon's video collection, for his invaluable advice on the use of video materials in class, for correcting my mistaken understanding of gender stereotypes in sci-fi movies of the 1950s, and for acquiring many of the titles that I use in the course for the library's permanent collection.

Serious work on the actual material for the book started with a second convergence of events, which began 10 years after the creation of the mini-course. The global economic crisis of 2009 resulted in the termination of a summer enrichment program in the sciences for talented high school students, of which I had served as the director for the previous 8 years. Official word of the termination came in March of 2009, leaving me in need of a creative outlet for the summer. I made a proposal to Gregg Franklin, newly appointed head of the physics department (2009–2013), to expand my popular mini-course on science and science fiction to a full-semester course. Unlike the mini-course, which was restricted to first-year students majoring in the sciences, this course would be open to anyone on campus, regardless of their major or year. The primary goal of the course would be to make science accessible to students in the fine arts and humanities, while keeping enough rigorous content to hold the interest of the more technically oriented students in science or engineering. This proposal was met with enthusiasm, not only by Gregg, but also by Kunal Ghosh, assistant head for undergraduate affairs in the physics department. Kunal has always been one of my biggest cheerleaders and for years had been encouraging me to expand the course and offer it to a broader audience. The timing couldn't have been more perfect to do just that. The announcement of the new course offering was made on campus just a few weeks before the May 2009 release of the new *Star Trek* movie, directed by J.J. Abrams. The university was quick to pick up on the connections, the most important of which was Zachary Quinto, a graduate of Carnegie Mellon's School of Drama (class of 1999), who was very well cast as the new Mr. Spock. I was honored to be interviewed by the university for a YouTube video promoting the expanded version of the course, which was uploaded in June 2009. A story about the course was also featured on the university's homepage. I'd like to thank Jocelyn Duffy and Carrie Chisholm for their work in promoting the course to the university community and to the outside world.

For three summers in a row (2009–2011), I offered the full-semester version of the course to an increasingly diverse audience and gradually refined the content. Many thanks to the students who took this early version of the course, as it flew under the radar, so to speak, and as we worked out what requirements it would fulfill for the university's various degree programs.

In April of 2011, I received an email out of the blue from Jace Harker, a publishing editor with Springer-Verlag, who was coming on a short visit to Pittsburgh. He asked if he could meet with me to discuss my work in undergraduate education in physics and to solicit ideas for new textbooks. Coincidentally, at my wife's suggestion, I had already been toying with the idea of writing my own book for the science and science fiction course. Jace was very enthusiastic about the possibility of publishing my lecture notes. But at that time they existed only in my head and in the form of a six-page spreadsheet of all the film references that I use day by day in the course. At his request, I created a detailed chapter outline, which he circulated for peer review at Springer. By the end of September, he sent me a draft of a contract to write the book. Thanks to my good friend Steve Paschall, who kindly offered to review the contract from an attorney's perspective. He raised several insightful questions, all of which were addressed to our satisfaction. The final contract was officially signed in October 2011.

Countless hours over the next 14 months were devoted to putting the ideas from my head onto the printed page, and doing the research to locate the important science references that I felt were needed to make a proper textbook. I owe a huge debt of gratitude to my wife, Janet, for her patience in watching lots of good (and not-so-good) science fiction with me, and for her valuable suggestions of material to include in the book. I'd like to extend a word of thanks to the Powe family—Janet's sister Treva, brother-in-law, Joe, and our niece, Cati—with whom we spent our 2012 Christmas vacation in Texas, for their patience as I spent hours at their dining room table, typing away on the first draft of the manuscript. Thanks also to the Quick family—Donnalynne, Janet's good friend from college, and her son, Austin (our godson) and daughter, Eliana—with whom we spent part of our summer vacation. They, too, had to put up with me, as I worked on the second draft at their home in California. The manuscript was delivered in nearly final form at the end of December 2012, with only three-and-a-half hours before the contract deadline. Many thanks to Mr. Ho Ying Fan at Springer for reading the manuscript and making helpful suggestions for revision, as well as for shepherding the manuscript through the editing and publication process.

Finally, I'd like to thank three groups of individuals, whose prayers and encouragement have sustained me through the entire journey: my Tuesday lunchtime discussion group, including David Anderson, Robin Capcara, John Dolan, Bob Griffiths, David Handron, John Ito, Christoph Mertz, and Gary Patterson; our Wednesday evening house group, consisting of Alan and Linda Komm, David, Debbie, and Karis Kornfield, Meredith Dobson, Jerry Martin, and Casey McDonald; and our Sunday morning fellowship group, which regularly includes Karen and Randy Woods, Carla and Jeff Sivek, Pam and Lou D'Abruzzo, Art Burt and Virginia Phillips.

Pittsburgh, PA — Barry B. Luokkala
May 2013

Preface to the Second Edition

The invitation to write the first edition of this book came as a surprise. I had never undertaken a writing project of this magnitude before. (The finished product ended up being longer than my physics PhD thesis.) But the request to write a second edition exceeded my expectations. While the reviews of the first edition were generally quite favorable, there were a few criticisms, which I have endeavored to take into consideration in preparing this revised and updated edition. I'm also grateful to many students and several colleagues, who carefully read the first edition and made helpful suggestions for changes. My sincerest thanks to Sam Harrison and colleagues at Springer for overseeing the editing and production of the second edition.

The overall structure is essentially unchanged. The material continues to be organized around the seven major questions of the first edition, spanning topics from the nature of space and time to the future of our technological society. The content within several chapters has been rearranged to enhance the clarity and flow. Some of the original artwork has been redrawn and 17 new illustrations have been added. Several new subtopics have been included and existing topics expanded. Some of these were inspired by sci-fi movies released since the publication of the first edition (*Interstellar*, *Chappie*, *Arrival*, to name just a few) or by works that had already been released prior to the first edition, but which I had not yet seen (The *Fringe* TV series, *Despicable Me*, *Robot and Frank*). Others were prompted by new discoveries or significant advances in science and technology (e.g., gravitational waves, machine learning, quantum computing, and controversial uses of gene editing). As was the case in the first edition, a few of the new references are to movies that do not fall into the category of science fiction (*Hidden Figures*, *Harry Potter and the Chamber of Secrets*), but nevertheless serve as good illustrations of the science concepts that have been added. And some of the new references are to movies that are definitely not new (*The Andromeda Strain*, *The Day the Earth Caught Fire*), but the subject matter remains very relevant to important issues facing us today. In all, more than 40 new references to specific scenes in more than 30 new (or newly rediscovered) movies and TV series episodes have been included.

To borrow a line from the 1995 version of *Sabrina* (not a science fiction movie but one of my favorites), “More isn’t always better. Sometimes it’s just more.” In the process of writing the second edition, I constantly had to be reminded of this bit of wisdom. Every new sci-fi movie or scientific discovery that came out since the first edition had to pass the test. If I chose to include it, would it be better or would it just be more? As a result, there were a number of possibilities for new material which, for various reasons, didn’t make the final cut. I owe a special debt of gratitude to my wife, Janet, for helping me to think this through and to exercise some restraint. I’m also grateful to her for keeping an eye out for interesting science news items and passing them on to me. Many of them have been included as new Exploration Topics at the end of several chapters. My hope is that this revised and expanded edition will be genuinely better than the first and not just more.

Pittsburgh, PA Barry B. Luokkala
July 2019

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About the Author

Barry B. Luokkala is a teaching professor and director of undergraduate laboratories in the department of physics at Carnegie Mellon University. He received his BS and MS degrees in Physics at the University of Pittsburgh, where he did experimental research in physics and chemistry of the ionosphere. He received his PhD in Experimental Condensed Matter Physics at Carnegie Mellon University. He also serves as program director for the Pennsylvania Governor's School for the Sciences and has been a science consultant for the Sloan Foundation Screenplay Competition in Carnegie Mellon's School of Drama.

Chapter 1
Introduction: Discerning the Real, the Possible, and the Impossible

Believe none of what you hear and half of what you see.
—Benjamin Franklin

Why, sometimes I've believed as many as six impossible things before breakfast.
—The Queen of Hearts
Alice in Wonderland

A major goal of the present work is to increase public awareness and appreciation of science, but the approach is somewhat unorthodox. We will use science fiction as a vehicle for exploring actual science and as a springboard for discussing some of the exciting topics that are currently being researched. Our examples will be drawn almost exclusively from film and television. Occasional references to a few of the classic works of science fiction literature are also included.

As we consider each of these sci-fi examples, we will attempt to discern whether what we see on the screen falls into one of the following categories:

- *realistic*—something that is it solidly grounded in real science, regardless of whether or not it has actually happened.
- *possible in principle*—something that has never happened before, but the laws of science do not necessarily rule it out. However improbable it may seem, it might simply be beyond our current technology.
- *impossible*—something that is total fantasy and impossible by any science we know.

When it comes to science fiction, the advice attributed to Benjamin Franklin, "Believe none of what you hear and half of what you see" may not be strict enough. We may end up believing even less than half of what we see. But there are some rare exceptions, in which the science is particularly well done, and you may be surprised at some of the things that are actually possible (at least in principle). We will also encounter a number of examples which fall into a fourth category:

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- *science fiction predicts the future*—many things currently exist that were purely in the imagination of the writers when the movie or television episode was produced. Thanks to breakthroughs in science and technology, what was once science fiction may now be real.

We begin with a few examples, which will set the tone for the rest of the book, while at the same time conveying a sense of the history of science fiction as a genre.

1.1 The First Sci-Fi Movie

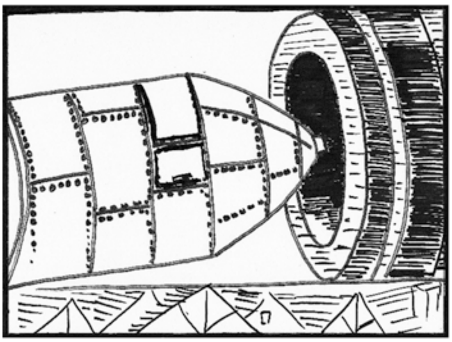
The earliest motion pictures, produced in the late 1800s, were typically only a few minutes in length and collectively covered a broad range of topics, from the mundane to the exotic. The first motion picture of significant length (roughly 20 min) also happens to be the first science fiction movie ever made and is well worth examining in detail. Produced in 1902, *Le Voyage dans la Lune* (A Trip to the Moon) was directed by George Méliès, who began his career as a stage magician [1, 2]. The 2011 movie *Hugo* is, in part, a somewhat fictionalized account of the life of George Méliès (played by Ben Kingsley) [3]. Because of its place in cinematic history (the first sci-fi movie ever made and the first film of any kind of significant length) and its subject matter (a trip to the moon, more than 60 years before such a thing was ever attempted in reality), *Le Voyage dans la Lune* provides an ideal starting point from which to launch our exploration of science through science fiction.

First, let's cover some of the key points of the story, as presented in the movie. The version described here is the one that is included in the excellent DVD collection, *Landmarks of Early Film*, which includes not only the silent motion picture, but also the accompanying narrated script and musical score [4]. In *Le Voyage dans la Lune,* Méliès weaves together elements from two sci-fi novels: the already well-known *De la Terre a la Lune* (Jules Verne, 1865) and the very recently published *First Men in the Moon* (H.G. Wells, 1901). Méliès also plays a leading role in the movie as the president of a council of "astronomers." In the opening scene, the president proposes a trip to the Moon. The means of locomotion, a capsule launched from a giant gun, is borrowed directly from Verne's novel, in which the gun is described as 900 ft long, with an inner diameter of 9 ft [5]. The president's proposal is received enthusiastically, except for a lone dissenter, who is ultimately persuaded by intimidation (the president throws his books and papers at him). However, as we explore the science in more detail, it will become clear that the rest of the council should have paid more attention to the dissenter.

The scenes which follow depict the construction of the space capsule and the casting of the giant gun. One event, in particular, might spark considerable discussion on matters of science, technology, industrial safety, and public policy. In a clear violation of modern occupational safety standards, the soon-to-be space travelers are shown walking through the construction site, without any personal protective devices (hardhats, safety glasses, lab coats, etc.). One of them is accidentally pushed into an open tub of nitric acid. Méliès surely included this for its slap-stick entertainment value. But imagine the biological, medical, and legal consequences of such an incident. It's not difficult to understand why, in today's society, it is increasingly rare for factories to offer guided tours of their facilities.

When the construction is completed, there is much pomp and circumstance, including a parade, the waving of French flags, and the playing of *La Marseillaise*. The capsule is loaded into the breach of the giant gun (Fig. 1.1), the fuse is lit, and instantly a puff of smoke appears out of the muzzle. The Moon comes into view, and soon the details of the face of the man in the Moon (the face of Méliès) become clear. The landing is shown, at first comically, as the capsule pierces the eye of the moon, and then somewhat more seriously, as the capsule glides gently onto the surface of the Moon.

The astronomers exit the space capsule to find a breathable atmosphere, gravity comparable to that on Earth, and snowfall. Numerous celestial oddities appear, including the rising of the Earth over the lunar horizon. As they explore a subterranean cavern, the astronomers find giant mushrooms and discover that an umbrella planted in the ground will take root and transform into a giant mushroom. The astronomers encounter an aggressive (or possibly just curious and hyperenthusiastic) race of beings, called the Selenites, or inhabitants of the Moon (a concept and terminology borrowed from Wells). They defend themselves against the Selenites (or is it an unwarranted imperialist attack on the indigenous population?) by striking them with their umbrellas. In so doing they discover that these are exceedingly fragile beings, which instantly disintegrate into a puff of smoke. The astronomers are eventually outnumbered, captured, and brought before the Selenite king. They manage to escape, vaporizing more Selenites in the process, and return to their space capsule, only to realize that they have no means of propulsion to get back to Earth. No worries. One of the astronomers (the president, himself?) tugs on a rope attached to the nose of the capsule, pulling it off the edge of the Moon, and it simply falls back to Earth. They splash down in the ocean and are recovered by a steamship, which tows them back to safety.



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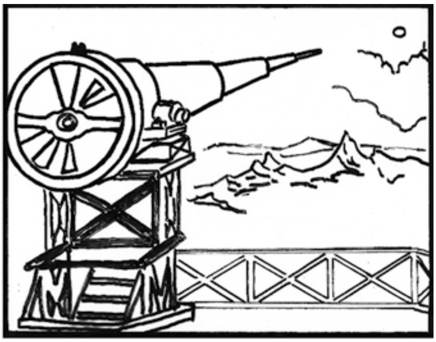

b

Fig. 1.1 Imagining a trip to the moon. A custom-built artillery shell (**a**) is loaded into the breach of a giant gun (**b**). The shell is designed to accommodate a handful of human passengers and is equipped with all the comforts of home. The gun is 900 ft long. The shell must reach escape velocity before leaving the muzzle of the gun. Will the travelers survive the launch?

1.2 Exploring the Science in *Le Voyage dans la Lune*

As we explore the science in this movie, we should keep in mind that Méliès was not primarily concerned with getting the science right. Rather, as a professional magician, he was more interested in exploring the kinds of illusions he could create with this new medium of motion pictures. Thus, Méliès was a pioneer of motion picture special effects. Nevertheless, it is fair game for us to critique the science content of the movie, and to discover how much of it, if any, is plausible.

Let's begin with the launch mechanism for the space capsule. Unlike actual spacecraft, which have been built on Earth since the mid-twentieth century, the space capsule in the movie carries no fuel and is not self-propelled. It is fired from a giant gun. Is this a plausible mechanism for achieving human spaceflight? Simply put, could the passengers in the space capsule survive a launch of this sort? Extensive research has been done on the biological effects of large accelerations—what happens to the human body when you experience a large increase in speed over a short period of time (as in a rocket launch), or when you are traveling at high speed and suddenly change direction (as in a fighter jet). Throughout this book, you will be invited to come up with estimates of various things, based on information presented in a movie or TV episode scene. But the information that you are able to gather by watching the scene may not be enough. You may need to make some additional assumptions, in order to calculate the result. The launch mechanism in *Le Voyage dans La Lune* provides a good illustration of the kind of information you can gather by watching the movie scene and the kind of additional assumptions you will need to make, in order to do a calculation. In particular, is there enough information in the movie to make an estimate of how much acceleration the passengers in the space capsule will experience during the launch? If not, what additional assumptions do we need to make, in order to do the calculation? Finally, we can compare the result of our estimate to known limits on the amount of acceleration that the human body can tolerate and decide whether or not the giant gun approach to spaceflight is plausible.

1.2.1 Motion with Uniform Acceleration

When an object experiences uniform (constant) acceleration, a, the position of the object, x, and the velocity of the object, v, at any time t, are described by the following equations:

$$x = x_o + v_o t + \frac{1}{2} a t^2 \tag{1.1a}$$

$$v = v_o + at. \tag{1.2a}$$

The constant x_o is the initial position, at time $t = 0$, and v_o is the initial velocity. We are free to choose the starting time, $t = 0$, to be any time that is convenient. The simplest choice is to define $t = 0$ to be the time at which the space capsule is at rest in the breach of the giant gun. This means that the initial velocity, v_o is zero. We are also free to choose our coordinates to make the initial position convenient. The simplest choice is $x_o = 0$. With these choices, the two equations (1.1a) and (1.2a) are simplified considerably, giving us:

$$x = \tfrac{1}{2}at^2 \tag{1.1b}$$

$$v = at. \tag{1.2b}$$

We want to come up with an estimate of the acceleration, *a*, of the space capsule. How much information do we know, and what additional information do we need in order to answer the question, Will the astronomers survive the launch?

We will consider two fairly straight-forward ways of estimating the acceleration of the space capsule, both of which involve using *information presented in the movie*, plus an additional set of *reasonable assumptions*, which are not explicitly presented in the movie. The first important observation to make is that the space capsule in *Le Voyage dans la Lune* has no internal propulsion system. It's just a giant artillery shell fired from a giant gun. So one reasonable assumption to make is that in order to leave Earth and travel to the Moon, the space capsule must achieve *escape velocity*: the minimum velocity needed to go into a stable orbit around the Earth. It's also important to realize that the space capsule must achieve escape velocity *before* it leaves the muzzle of the gun. Once the capsule leaves the gun, the expanding gas from the explosion of the gunpowder is no longer of any use to increase the speed of the capsule. In actuality, a little more than escape velocity is needed, if the capsule is to overcome the effects of air resistance. Once the capsule leaves the muzzle of the gun, not only is there no more propelling force from the expanding gas of the explosion, but also is there a resistive force that will slow it down as it travels through the Earth's atmosphere. But since all we want is an estimate of the acceleration, we can ignore air resistance. Escape velocity will be good enough for our purpose.

Example 1.1: Estimating the Acceleration of the Space Capsule (Simple Approach)

The simplest approach to estimating the acceleration of the space capsule in *Le Voyage dans la Lune* is to take a guess for the time, *t*, that the capsule spends inside the gun. Based on what we see in the movie, it takes about 1 s from the moment the gun is fired until the capsule leaves the gun. We know that the final velocity of the capsule must be equal to escape velocity (approximately 11.2 km/s). So we can solve Eq. (1.2b) for the acceleration, *a*, and substitute our values for the time, *t*, and velocity, *v*.

$$\begin{aligned} a &= v/t \\ &= (11.2\,\text{km/s})/(1\,\text{s}) \\ &= 11{,}200\,\text{m/s}^2 \end{aligned} \tag{1.3}$$

Example 1.2: Acceleration of the Space Capsule Using Data from Jules Verne's Novel

An alternative approach to estimating the acceleration involves making another reasonable assumption, which is not explicitly presented in the movie. Recall that the movie is based, in part, on a novel by Jules Verne, in which the length of the giant gun is said to be 900 ft. Instead of taking a guess for the time, t, at which the capsule leaves the muzzle of the gun after it is fired, we could use the known final velocity (escape velocity) and the distance traveled to reach escape velocity (the length of the gun). We can combine the two equations (1.1b) and (1.2b) to eliminate the time, t. If we solve Eq. (1.2b) for t, and substitute into Eq. (1.1b), we get

$$a = v^2/2x. \tag{1.4}$$

We can now calculate the acceleration using escape velocity for v and the length of the gun for x. But in order to do the calculation, we need to put all quantities in a consistent set of units (e.g., velocity in m/s, and distance in m). We convert the length of the gun from feet to meters using the approximate conversion factor of 0.305 m/ft: (900 ft)(0.305 m/ft) = 274.5 m. Finally, using Eq. (1.4), we calculate the acceleration:

$$\begin{aligned} a &= (11.2\,\text{km/s})^2/2(274.5\,\text{m}) \\ &= 228{,}488\,\text{m/s}^2 \end{aligned}$$

Note that the results of Examples 1.1 and 1.2 do not agree with each other. If you are puzzled by this apparent discrepancy, keep in mind that we made *different assumptions* in each case. In the first example, we simply took a guess for the time, t, based on what we saw in the movie. In the second example, we used information that was not actually presented in the movie, but which came from the novel on which the movie was based. The result that you get when you do any calculation will depend on the assumptions that you make. When you are asked to do calculations later in this book, be sure to state your assumptions clearly.

Example 1.3: Comparing Space Gun Acceleration to the Acceleration Due to Gravity

Having estimated the acceleration experienced by the space travelers in *Le Voyage dans la Lune* by two different methods, we are now in a position to ask whether or not they will survive the launch. Let's first compare the estimated acceleration to the average acceleration due to gravity on Earth: g = 9.8 m/s^2. If we divide the acceleration from Example 1.1 by 9.8 m/s^2, we find that the travelers will experience an acceleration of more than 1100 times the acceleration due to gravity. Similarly, the result from Example 1.2 turns out to be over 23,000 times the acceleration due to gravity. Is this safe? How does this compare to real-life space launches from Earth and to the maximum acceleration that the human body can tolerate without serious damage? The answers to these questions are left as a topic for exploration.

Exploration Topic 1.1: The Biological Effects of Large Acceleration (Is It Safe to Launch Humans into Space from a Giant Gun?)

(a) Consult a reliable source of information, such as NASA's web site, to find out how much acceleration is experienced by real-life astronauts, when they are launched into space. The acceleration is typically expressed as a multiple of g, the acceleration due to gravity on Earth, and is sometimes referred to as the number of "*G*"s.
(b) The 1979 movie *Moonraker* includes a scene in which British secret agent James Bond (played by Roger Moore) is exposed to near-lethal acceleration in a flight training centrifuge [6]. According to the scene, most people will pass out if they experience an acceleration of seven times the acceleration due to gravity (without the benefit of a special pressurized flight suit to maintain blood flow to the brain). Twenty times the acceleration due to gravity is lethal. Do some research to verify (or refute) this information. How many "*G*"s can a human tolerate without passing out? What is the maximum number of "*G*"s that can be tolerated without serious or permanent injury? Does it make a difference whether the acceleration is along the head-to-foot direction through the body or the front-to-back direction? Why or why not? How many "*G*"s are fatal to humans?
(c) How does the acceleration experienced by the astronomers in the giant space gun (the results of Examples 1.1, 1.2 and 1.3) compare to a typical NASA space launch? Is the giant space gun a plausible approach to human space flight?

The results of our calculations suggest that the council of astronomers should have listened to the lone dissenter and would have done well to explore other options for their trip to the Moon. But remember that the director, Méliès, was concerned primarily about entertainment (creating illusions), and not about getting the science right. Despite the completely implausible (lethal!) launch mechanism, the astronomers in the movie actually do survive the launch and land on the Moon.

1.2.2 Imagining Human Exploration of the Moon

As we have just seen, the mechanism of human space flight imagined in *Le Voyage dans la Lune* is completely implausible—the astronomers would have died before they even left the Earth. Although humans did, in fact, land on the Moon more than 60 years later (Apollo 11, July 20, 1969), the way that it was done was nothing at all