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Writing quantum: how quantum mechanics is narrated and explained in popular science books

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Abstract

This thesis explores how quantum mechanics is communicated in popular science books, with particular attention to the role of mathematics, technical jargon and history of physics. Focusing on a selection of 26 books written for non-specialists, it examines how authors explain complex concepts without relying heavily on mathematics or technical detail, often the defining features of quantum physics in academic contexts.

Key themes include the role of metaphor and analogy, the minimization of mathematics, the use of narrative to smooth over conceptual "hills" in comprehension, and the treatment of interpretative debates, especially the presentation of the many-worlds interpretation as an underdog. Particular attention is paid to how different texts balance accuracy with accessibility, and where they may cross the line into oversimplification or, in some cases, pseudoscience.

This thesis offers a critical framework for thinking about how quantum mechanics is popularized, and why it matters. By identifying common patterns and rhetorical moves, the goal is to support more thoughtful science communication—not just for quantum physics, but for any complex, abstract subject that demands clarity, care, and creativity.

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Chapter 1

Introduction

1.1 A Brief History of Science Communication

Gitte Meyer's article *In Science Communication, Why Does the Idea of a Public Deficit Always Return?* provides a compelling historical lens on the deficit model in science communication. As she explains, for much of its history, science communication was understood primarily as a didactic enterprise [4]. This early conception positioned scientists as the holders of knowledge and the public as lacking it, much like a teacher–student relationship. The fundamental assumption was that the public possessed a knowledge deficit that could be remedied through instruction and dissemination.

From the early development of modern science, numerous efforts aimed to extend scientific knowledge beyond expert communities and to convince non-scientists of its value. These efforts often rested on Enlightenment ideals. In his 1667 treatise *The History of the Royal Society*, Thomas Sprat described science as the spread of a "Universal Light" [5], reflecting a view of science as a secular, almost spiritual, good. One might even read a slight religious undertone in this framing: scientists as the spreaders of the gospel of reason.

However, it was not until the 1980s that science communication became the subject of critical research, particularly within the social sciences. The so-called deficit model was explicitly named and problematized during this period. David Dickson clarifies the origins of the phrase: "The original purpose of the phrase, coined by social scientists studying the public communication of science in the 1980s, was not to describe a mode of science communication. Rather it was to characterize a widely held belief that underlies much of what is carried out in the name of such activity" [6].

According to this model, public skepticism or lack of enthusiasm for science and technology was attributed to ignorance or insufficient knowledge. The proposed solution was straightforward: deliver accurate scientific information, and the "knowledge deficit" would be corrected.

Concerns about the public's understanding of science intensified in the mid-1980s, particularly after the publication of the influential Bodmer Report. As documented by Bennett and Jennings [7], and further analyzed by Wilkinson [8], this period marked a turning point in institutional approaches to science communication. Stephen Hilgartner described this dominant view as one that casts the public as passive receivers of expert knowledge, a framing that has political as well as conceptual implications [9]. Around the same time, Jon D. Miller conducted one of the first major empirical studies on scientific literacy, concluding that "the majority of adults [are] scientifically illiterate" [10], sparking calls for renewed education and outreach efforts.

The information-transfer model of communication, closely aligned with the deficit model, also became influential. It draws heavily on the linear framework of Shannon and Weaver's *The Mathematical Theory of Communication*, which treats communication as the unidirectional transmission of information from sender to receiver [11]. This model positions the scientist as the source and the public as the recipient, with understanding presumed to follow automatically from exposure to information. As Bucchi argues, this linear model ultimately reinforces the core assumptions of the deficit model: that misunderstanding results from a lack of facts and can be corrected by simply providing more [12].

Despite significant investment and institutional support, this approach yielded only modest outcomes. Kanta Sarasvati Monique Dihal, in her historical analysis of quantum physics in popular science, points to the limitations of treating public engagement as a matter of simplification and transmission [13]. Over the past two to three decades, both the theory and practice of science communication have undergone a noticeable shift. Trench and Bucchi describe this evolution as the emergence of science communication as a formal field, with its own methods, theories, and internal debates [14].

As part of this shift, the vocabulary of science communication has also changed. Where once terms like "popularisation" and "public understanding of science" dominated, more recent discourse has adopted the language of "dialogue", "engagement", and "participation". Jane Gregory emphasizes the UK's central role in this evolution [15], while Gregory and Lock write that new approaches to science communication "value the knowledge of scientists and non-scientists alike, which meet in policymaking" [16]. These shifts suggest a more reciprocal understanding of communication, one that seeks to replace unidirectional flow with mutual exchange.

To conclude, it is important to distinguish between physics education and physics communication. Evaluating popular physics books using the standards of physics education misrepresents their intent. These books are not physics textbooks, and should not be judged as "diet" versions of them.

A physics textbook is meant to consolidate knowledge for students, enabling structured learning and academic progression. Popular physics books, by contrast, often aim to provoke curiosity, provide narrative richness, or foster a broader appreciation for scientific research among the general public. Their role is cultural as much as it is informational, and the distinction is a meaningful one.

1.2 C. P. Snow and the "two cultures"

In 1959 British scientist and novelist Charles P. Snow held a very influential lecture at Cambridge, which was published as a book later that same year, titled "The Two Cultures and The Scientific Revolution". This work became very influential, was widely read in both Europe and North America, and clearly resonated with a lot of academics, whether they were in the humanities or in the sciences. The most famous passage from this lecture is about intellectuals in the humanities, of which Snow says:

> "As with the tone-deaf, they don't know what they miss. They give a pitying chuckle at the news of scientists who have never read a major work of English literature. They dismiss them as ignorant specialists. Yet their own ignorance and their own specialization is just as startling. 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 how many of them could describe the Second Law of Thermodynamics. The response was cold: it was also negative. Yet I was asking something which is about the scientific equivalent of: "Have you read a work of Shakespeare's?" [...] So the great edifice of modern physics goes up, and the majority of the cleverest people in the western world have about as much insight into it as their neolithic ancestors would have had" [17].

The author then goes on to discuss some of the possible causes for the rift between science and the humanities, including the aftermath of the industrial revolution, the scientific revolution, British classism and more. He finishes the lecture by pointing out that this divide between the two cultures is a detriment to intellectuals, and both sides are impoverished by it.

As someone with both a classical high school diploma and a Physics Bachelor's Degree, I like to think that the divide between the two cultures is not as wide as Snow perceived it to be in 1959. Still, the difference between students of science and students of the humanities is not small. For example, the two groups seem to still have a significant gap in scientific literacy [18].

In such a context, popular science books occupy a special place. To quote Elizabeth Leane in "Reading Popular Physics", for the popular physics writer "some form of appropriation of literary technique is inevitable; for, unlike the writer of professional scientific discourse, who can assume his/her reader's interest, the popular science writer must capture the reader's attention and imagination just as a novelist must, and to do this, s/he must borrow from the novelist's tool-kit" [19].

The attempts of scientists to breach outside of their ivory tower are not always appreciated. Popular physics books provide a meeting point for the two cultures, and can therefore be a source of conflict. As the popular physics book has slowly filled the shelves of bookstores and libraries, some authors who don't have a scientific background have grown spiteful. The hilariously confrontational prose of Lucy Ellmann comes to mind, from her 1998 article in The Guardian titled "No Holes Barred", which reads: "Ten years since Hawking's book –that incomprehensible tome on time– and now it's considered normal for science books to fill the bestsellers list, and for their authors to appear on TV". One might wonder what are scientists to do, if they want to please Ellmann. Does she want popular science authors to strive to be less "incomprehensible", presumably then filling even more of the bestsellers list? Or would she prefer that scientists remain "anything but popular", as she says they used to be (and, I suspect, thinks they should be) just a few sentences before?

Outside of the snarky opinions of some authors, the popular physics book seems to enjoy an unprecedented success. In the last 40 years, scientists have put more effort than ever to reach out to laypeople, and the efforts are reflected in sales numbers [20]. So the "two cultures" debate is as relevant as ever.

1.3 Why Focus on Popular Quantum Mechanics Books?

The decision to focus on popular physics books in this thesis is motivated both by academic interest and personal experience. My background is in physics, but I have also worked as a science communicator outside of academia, where I developed a deep appreciation for the challenges of translating abstract scientific ideas for general audiences. Over the years, I've read widely in both science and literature, and among all scientific topics, quantum mechanics continues to fascinate me the most. Its paradoxes, counterintuitive behavior, and philosophical depth not only stretch the imagination but also provoke a sense of wonder that few other fields can match.

Books, in particular, have played a central role in shaping my relationship to science. As a reader, I've found that a well-crafted popular science book can linger in the mind long after the last page is turned. Books demand time, focus, and attention; they cultivate a slow, immersive mode of engagement that aligns beautifully with the complexity of physics. For readers who voluntarily choose to spend their leisure time learning about quantum mechanics, the investment is both intellectual and emotional. For science communicators, this makes the format uniquely powerful and uniquely responsible.

This thesis began, in part, with simple but persistent questions: what makes a quantum physics book good? What qualities make some books compelling, memorable, and illuminating, while others struggle to connect? Through this research, I hope to begin answering that question, not only to deepen my own understanding of science writing, but also to develop a set of informal guidelines that might support others who, like me, care about bringing quantum physics to life for diverse audiences. This project is not just an academic exercise; it's a reflection of my own curiosity and my ongoing effort to communicate science in a way that is clear, meaningful, and inspiring.

Beyond personal motivations, there are also broader disciplinary assumptions that make the field of physics particularly compelling within the context of popular science. As Elizabeth Leane observes, "Physics carries a set of associations that make it both particularly problematic and particularly fruitful in the context of this study" [19]. The cultural hierarchy of sciences, first formalized by Auguste Comte, elevates physics above other fields due to its mathematical elegance and its foundational focus on space, time, and matter. Comte's "scale of relative perfection" ranked sciences according to their generality and abstraction, placing physics at the top because of the precision and mathematical treatment it allows [21].

This privileged position has influenced how physics is communicated. Its perceived purity, rigor, and universality make it a kind of gold standard in science writing. As Stefan Collini puts it, physics often functions as "a kind of gold standard against which weaker or debased forms of science could be measured" [22]. The infamous quote attributed to Ernest Rutherford "all science is either physics or stamp collecting" illustrates this deeply entrenched attitude [23]. Even contemporary writers such as Paul Davies acknowledge this disciplinary hubris, stating: "Physics is the most pretentious of the sciences, for it purports to address all of physical reality... the entire universe, from the smallest fragment of matter to the largest assemblage of galaxies, becomes the physicist's domain" [24].

Within physics, quantum mechanics is a particularly rich area to explore. Most popular physics books tend to focus on cosmology or relativity, perhaps because of their visual appeal and narrative scale [19]. In contrast, quantum mechanics is more abstract, often stranger, and harder to visualize, making it both more difficult and, to my mind, more rewarding to write about. It invites metaphor, demands clarity, and stretches both writer and reader in creative ways.

My own fascination with quantum mechanics stems not just from its scientific content, but also from its interpretive and philosophical depth. Through science communication, I've made modest contributions to helping others understand this field, but this thesis has offered a chance to examine it more rigorously. In doing so, I aim to build on my experience and develop a stronger foundation for future writing, both for myself and for anyone interested in making sense of this profoundly beautiful and complex theory.

The chapters that follow develop this inquiry in several steps. In Chapter 2, I outline the methods and materials of the study, introducing the corpus of twenty-six popular quantum mechanics books and the criteria for their selection. Chapter 3 examines how these works narrate quantum mechanics, focusing on mathematics, jargon, historical framing, metaphor, and narrative strategies, including the recurring portrayal of the many-worlds interpretation as an underdog. Chapter 4 turns to close readings of selected books, highlighting the distinctive choices and rhetorical styles of individual authors. Chapter 5 addresses cases where quantum mechanics is misunderstood or distorted, from oversimplified children's books to the more radical reinterpretations of the 1970s, and reflects on the consequences of such misrepresentations. Together, these chapters aim to build a critical picture of how quantum mechanics is communicated to general audiences, what patterns emerge across different texts, and what this reveals about the possibilities and challenges of science communication.

Chapter 2

Methods and materials

The following is a list of all the books analyzed in this thesis, in chronological order of publication:

1. Werner Heisenberg - *Physics and Philosophy: The Revolution in Modern Science* (1958)
2. Banesh Hoffmann - *The Strange Story of the Quantum* (1965)
3. George Gamow - *Mr Tompkins in Paperback* (1965, combines earlier works from 1940 and 1944)
4. George Gamow - *Thirty Years That Shook Physics: The Story of Quantum Theory* (1966)
5. Fritjof Capra - *The Tao of Physics: An Exploration of the Parallels between Modern Physics and Eastern Mysticism* (1975)
6. Heinz R. Pagels - *The Cosmic Code: Quantum Physics as the Language of Nature* (1982)
7. John Gribbin - *In Search of Schrödinger's Cat: Quantum Physics and Reality* (1984)
8. Alastair I. M. Rae - *Quantum Physics, Illusion or Reality?* (1986)
9. Paul Davies - *Other Worlds* (1988)
10. Richard Feynman, Robert Leighton, Matthew Sands - *Six Easy Pieces: Essentials of Physics Explained by Its Most Brilliant Teacher* (1994)
11. Murray Gell-Mann - *The Quark and the Jaguar: Adventures in the Simple and the Complex* (1995)

12. Robert Gilmore - *Alice in Quantumland: An Allegory of Quantum Physics* (1995)

13. David Deutsch - *The Fabric of Reality: The Science of Parallel Universes and Its Implications* (1997)

14. Brian Greene - *The Elegant Universe: Superstrings, Hidden Dimensions, and the Quest for the Ultimate Theory* (2000)

15. John Polkinghorne - *Quantum Theory: A Very Short Introduction* (2002)

16. Tony Hey, Patrick Walters - *The New Quantum Universe* (2003)

17. Alastair I. M. Rae - *Quantum Physics: A Beginner's Guide* (2005)

18. Manjit Kumar - *Quantum: Einstein, Bohr and the Great Debate About the Nature of Reality* (2008)

19. Chad Orzel - *How to Teach Quantum Physics to Your Dog* (2010)

20. Jim Baggott - *The Quantum Story: A History in 40 Moments* (2011)

21. Brian Cox, Jeff Forshaw - *The Quantum Universe (And Why Anything That Can Happen, Does)* (2012)

22. Carlo Rovelli - *Seven Brief Lessons on Physics* (2015)

23. Michael Raymer - *Quantum Physics: What Everyone Needs to Know* (2017)

24. Anil Ananthaswamy - *Through Two Doors at Once: The Elegant Experiment That Captures the Enigma of Our Quantum Reality* (2018)

25. Philip Ball - *Beyond Weird: Why Everything You Thought You Knew about Quantum Physics Is Different* (2018)

26. Carlo Rovelli - *Helgoland* (2020, English translation published in 2021)

This selection aims to provide a comprehensive overview of popular works on quantum mechanics spanning several decades. As Leane notes [19] (and as will be discussed in further chapters) most popular books on quantum mechanics have been published after the 1970s, particularly following the success of *The Tao of Physics* in 1975, which sparked significant interest from the publishing industry in quantum mechanics and modern physics. Consequently, the majority of the books analyzed in this thesis come from the last forty years.

The works were primarily chosen on the basis of commercial success and contemporary relevance. Particular attention was given to recent titles, such as Philip Ball's

Beyond Weird and Anil Ananthaswamy's *Through Two Doors at Once*. Carlo Rovelli, widely regarded as one of Italy's most influential popularizers of quantum mechanics, is represented by two of his books. Some works were included for their distinctive perspectives, for example David Deutsch's *The Fabric of Reality*, which played a central role in popularizing the many-worlds interpretation.

Unlike most previous studies of popular quantum mechanics literature, which typically examine less than ten titles [13] [19], this thesis analyzes 26 books. This broader scope allows for a more nuanced understanding of the evolution of themes, styles, and perspectives within the genre.

Chapter 3

How quantum mechanics is narrated in popular physics books

3.1 The Role of Mathematics in Popular Quantum Mechanics Books

Mathematics is widely recognized as the foundational language of physics. A practicing physicist, by the end of formal academic training, acquires fluency in advanced mathematical tools that allow for the formulation and analysis of physical theories. These tools are not just supplementary to physics: they are constitutive of it. Despite this intrinsic link between mathematics and physics, popular books on quantum mechanics often minimize, omit, or sideline formal mathematical content.

In several of the books analyzed, equations do appear, though rarely in a central or sustained way. Out of the 26 titles, at least 11 feature one or more equations. Some use only the simplest expressions: for example, Pagels includes Boyle's law, $P \times V = T$ [25], while others refer to $E = mc^2$ [26, 27, 28]. Among the outliers is Gamow's *Thirty Years That Shook Physics*, which embraces mathematics more enthusiastically. The book presents key formulas such as $E = h\nu$ in its discussion of light quanta and even uses equations as a visual motif in its illustrations (see Figure 3.1) [29]. A similar openness appears in *Mr. Tompkins in Paperback*, where both Einstein's Field Equations and Schrödinger's Equation are quoted and explained [30]. Still, in many other works, equations are mentioned only as a form of symbolic reference, not as part of the explanatory apparatus, such as Gell-Mann's inclusion of Maxwell's Equations or Raymer's note on Bell's Inequality [31, 32].

In other cases, authors translate equations into everyday language, embedding them in prose rather than typeset math. Gribbin, for instance, introduces Newton's laws of motion without notation:

"Usually, this second law is expressed slightly differently: force equals mass

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pant of the Carlsberg Mansion died in the early thirties, Bohr and his family moved into it. In Fig. 14 is given a sketch of a tie which was made for an anniversary of the well-known Danish biochemist Linderstrøm Lang, who for many years was the director of Carlsberg Brewery's research laboratory, and shows a bottle of

Fig. 14. Carlsberg Beer and its consequences.

Figure 3.1: Gamow uses equations as an aesthetic choice

times acceleration. And Newton's third law tells us something about how the object reacts to being pushed around: for every action there is an equal and opposite reaction" [1].

Similarly, Kumar provides a verbal interpretation of Einstein's photoelectric equation:

> "Einstein encoded all this in a simple equation: the maximum kinetic energy of an electron emitted from a metal surface was equal to the energy of the light-quanta it absorbed minus the work function. [...] The gradient of the line, irrespective of the metal used, would always be exactly equal to Planck's constant, h" [27].

These strategies reflect a broader ambition shared by many science communicators: to offer an accessible, "translated" version of quantum theory that does not rely on mathematical literacy. Numerous authors explicitly affirm this intent. Davies, for example, assures readers that "no previous knowledge of science or philosophy" is required, and that concepts are explained "in the most elementary language" [24]. Gilmore opts for allegory to bridge abstract physics and familiar experience [33], while Heisenberg concedes the necessity of plain language when communicating to non-specialists [34]. Similarly, Raymer explains his effort to use "as ordinary-sounding language as possible to describe technical terms and concepts" [32]. In most cases, the implicit goal of a popular book on quantum mechanics is to capture the conceptual core of the theory without demanding formal training from the reader.

This stance corresponds to assumptions about the audience. The typical reader of such books is presumed to be intellectually curious, yet not mathematically trained. Greene's stated aim in writing *The Elegant Universe* was to make advanced physics "accessible to a broad spectrum of readers, especially those with no training in mathematics or physics" [35]. Hey and Walters define their audience as the "educated reader" or interested youth [36]. *Six Easy Pieces* was conceived as a nontechnical primer that distills Feynman's science for a broad audience [37]. Rae asserts that even the conceptual tensions in quantum physics can be addressed without mathematical rigor [26], and Cox and Forshaw claim that "everyone can understand the deepest questions of science" [28]. Raymer similarly frames his book as a lay-accessible introduction to quantum theory [32]. Orzel's stated motivation for writing the book is to "teach more people about quantum"[38]. The reputation of quantum mechanics as intellectually impenetrable is directly challenged by Philip Ball, who states that "Quantum mechanics is in a certain sense not hard at all. It is baffling and surprising, and right now you could say that it remains cognitively impenetrable. But that doesn't mean it is hard in the way that car maintenance or learning Chinese is hard [...] plenty of scientists find the theory easy" [39].

The most salient difference between textbooks and popular treatments is precisely this handling of mathematics. As noted by Dihal, foundational equations such as

Schrödinger's are rarely central to the narrative in popular books, while more iconic, metaphor-driven constructs such as Schrödinger's cat are almost always included [13]. This shift in emphasis may subtly alter readers' perceptions of physics itself, suggesting, perhaps, that quantum theory is more about paradoxes and analogies than about formal systems and solutions.

Yet many authors acknowledge the tension. Polkinghorne, Heisenberg, Cox and Forshaw, Rae, and Davies all recognize that quantum mechanics is fundamentally mathematical [40, 34, 28, 26, 24]. Hoffmann claims to write "without mathematics yet without important omission of concept" [41], suggesting that conceptual completeness can be retained even when formalism is absent. Still, authors frequently take care to reassure the reader: Cox and Forshaw encourage those "who find the maths difficult" to "skip over the equations without worrying too much," emphasizing that the "key ideas" will be conveyed independently of the math [28], and Rae weaves subtle assumptions about his readers into his reassurance, telling them that his "mathematical boxes" use "only the basic mathematics many readers will have met at school" and can be omitted without "missing the main strands of the argument" [26]. Gilmore's character, the "Quantum Mechanic", states, "I am afraid that I cannot really explain what is happening to the electrons [...] but I can tell you how we describe what goes on" [33]. Philip Ball is a bit more ambitious in his promises, saying that the "most fundamental message of quantum theory isn't a purely mathematical one" and that the math, though "fearsome", is "really just a set of rules". He suggests that if one can grasp the "new and unfamiliar logic", then "the quantum world may stop seeming weird and become just another place". He also points out that the Uncertainty Principle "can be understood in terms of school-level math". Ball relays the hope, shared by John Wheeler and Chris Fuchs, that one day a "story about quantum mechanics – 'literally a story, all in plain words' – that is 'so compelling and so masterful in its imagery that the mathematics of quantum mechanics in all its exact technical detail will fall out as a matter of course'" will emerge. He also critiques the current formulation of quantum theory as "far more baroque than it needs to be" [39].

In books that do include equations, the layout itself often supports this skippability. Mathematics is set apart, placed in appendices, boxed summaries, or clearly optional chapters. Greene forewarns readers that abstract material can be skipped "with minimal impact on the book's logical flow" [35]. Hey and Walters similarly reassure their readers that mathematical interludes are not necessary for comprehension [36], and Polkinghorne confines most formalism to an appendix [40]. Rovelli includes only one equation in his *Seven Brief Lessons on Physics*, Einstein's equation of general relativity, which he "cannot resist giving here", warning his readers that they "almost certainly will not be able to decipher it" but also that "anyone reading this will still be able to appreciate its wonderful simplicity" [42].

This editorial strategy has both strengths and drawbacks. On the one hand, it democratizes access, opening quantum discourse to a broad readership. On the other, it risks presenting a fragmented or overly intuitive vision of physics, one that decouples mathematical reasoning from conceptual insight. The introduction to *Six Easy Pieces* praises Feynman for his ability to "bring out the essence of a deep principle, without obscuring it in incidental or irrelevant details" [37]. Yet such framing may inadvertently imply that mathematics is incidental or even obstructive, an unfortunate message, given that for physicists, the beauty and truth of a theory often lie precisely in its mathematical formulation.

A particularly emblematic case, though not a book specifically about quantum mechanics, is Stephen Hawking's *A Brief History of Time.* Famously, Hawking noted that he was warned each equation would halve his readership, and as a result, he included only one: $E = mc^2$. While the minimization of equations predates Hawking, the commercial success of his book likely solidified this editorial caution into industry standard. Since then, the tendency to avoid equations has been pervasive, influencing both the style and substance of popular science communication.

In summary, the marginalization of mathematics in popular quantum mechanics books serves to widen access, but also contributes to a particular portrait of physics, one that elevates metaphor and narrative while backgrounding the formal tools through which the discipline advances. This editorial compromise is understandable and often necessary, but it invites further reflection on how best to represent science to non-specialists: faithfully, creatively, and responsibly.

3.2 Jargon and Technical Knowledge

The relatively diminished role of mathematics in popular physics writing is particularly notable when contrasted with the prominence of technical terminology, or jargon. Despite the stated intentions of many popular science authors to "translate" quantum mechanics into accessible language for lay audiences [24, 33, 2, 34, 35], technical vocabulary is widely employed throughout most of the works analyzed.

Frequently, new technical terms are introduced in their own dedicated paragraphs. For instance, Gribbin's explanation of a potential well provides a vivid illustration:

> "The nucleons are held together inside the nucleus by the strong nuclear force, but if an alpha particle was just outside the nucleus it would be strongly repelled by the electric force. The combined effect of the two forces is to make what physicists call a "potential well". Imagine a cross-section through a volcano with gently sloping sides and a deep crater. A ball placed just outside the crater rim will roll away down the outside of the mountain; one placed just inside the crater rim will fall into the heart of the volcano. Nucleons inside the nucleus are in a similar situation—they are inside the well at the heart of the atom, but if they could just get over the "rim", even by a tiny amount, they would "roll away", pushed by the electric force" [1].

This description is accompanied by a visual representation (Figure 3.2) that reinforces the metaphorical framing.

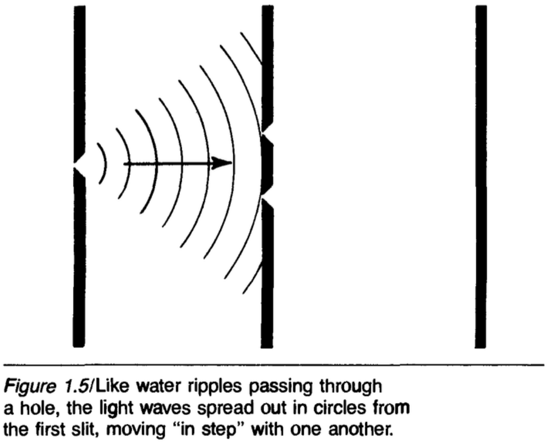


Figure 3.2: The picture and caption that Gribbin uses to explain what a potential well is [1]

In other instances, technical language is more seamlessly integrated into the prose:

> "Unable to go further theoretically without experiments with a real blackbody to guide him, Kirchhoff nevertheless pointed physicists in the right direction. He told them that the distribution being independent of the material from which a blackbody was made meant that the formula should contain only two variables: the temperature of the blackbody and the wavelength of the emitted radiation. Since light was thought to be a wave, any particular colour and hue was distinguished from every other by its defining characteristic: its wavelength, the distance between two successive peaks or troughs of the wave. Inversely proportional to the wavelength is the frequency of the wave – the number of peaks, or troughs, that pass a fixed point in one second. The longer the wavelength, the lower the frequency and vice versa" [27].

Here, Kumar provides a brief definition of "wavelength" while presuming a degree of familiarity with other terms such as "distribution" and "emitted radiation". His measured and deliberate prose style allows for the inclusion of such jargon without disrupting the overall readability.

A comparable strategy can be observed in the treatment of technical knowledge. Some authors include specific numerical values that may be either scientifically relevant or simply illustrative, such as the age of the universe in seconds [1], the value of Planck's constant [28], the speed of light [26], the so-called "magic numbers" in nuclear physics

[41], or what and Angstrom is [37]. In some cases, these references precede discussions of scientific notation [28, 1, 40].

The degree of technical detail included is ultimately a matter of stylistic preference. Consider, for example, the contrast between Kumar and Ananthaswamy:

> "The Swedish physicist, Anders Ångström, had in the 1850s measured the wavelengths of the four lines in the red, green, blue and violet regions of the visible spectrum of hydrogen with remarkable accuracy. Labelling them alpha, beta, gamma and delta respectively, he found their wavelengths to be: 656.210, 486.074, 434.01 and 410.12 nm. In June 1884, as he approached 60, Balmer found a formula that reproduced the wavelengths (λ) of the four spectral lines: $lambda = b[\frac{m^2}{m^2-n^2}]$ in which m and n are integers and b is a constant, a number determined by experiment as 364.56 nm" [27].

> "Bell showed that if Einstein is correct, the correlation has to be less than or equal to a certain amount (hence it's called the Bell inequality test). More specifically, Bell showed that if quantum mechanics is correct and the measurement of a photon's polarization by Alice does instantly influence the state of Bob's photon (and vice versa), then the amount of correlation should exceed that threshold, thus violating the inequality. If so, the quantum world would be manifestly nonlocal" [2].

While Kumar provides precise numerical data and an explicit formula, Ananthaswamy opts for a more conceptual description, eliding the mathematical specifics in favor of narrative clarity.

Another example of avoiding jargon for the sake of accessibility is found in *Six Easy Pieces*: Feynman talks about "lumpiness" [37] in chapter 6, when he describes the double slit experiment, instead of using the word "quantization". When explaining the double slit experiment with waves, he says "the intensity of the wave can have any value at all. We would not say that there was any "lumpiness" in the wave intensity" [37]. Later, when talking about the same experiment with electrons, he says "all the "lumps" are the same size: only whole "lumps" arrive, and they arrive one at a time at the backstop. We shall say: electrons always arrive in identical "lumps"" [37].

Science communicators are frequently advised to eliminate jargon in order to enhance accessibility [43, 44, 45]. In physics, a commonly cited challenge is the repurposing of familiar terms with new, technical meanings, which can create conceptual friction for general readers [46]. However, in the context of quantum mechanics, this issue is arguably less pronounced. Many of the terms used, such as "spin," "quark," or "photon", were introduced specifically to describe novel concepts and lack significant everyday connotations. Heisenberg considered this a possible positive, saying that complementarity encourages "an ambiguous rather than an unambiguous language" and declares this trend "in many ways quite satisfactory, since it reminds us of a similar use of language in daily life or in poetry" [34].

Taking all these considerations into account, it becomes evident that there is no universally "correct" amount of jargon or technical content in popular science writing. These decisions depend on each author's stylistic goals, the level of depth they wish to achieve, and their assumptions about the reader's interests and prior knowledge.

The widespread inclusion of jargon, despite the general avoidance of mathematical formalism, reveals an intriguing set of assumptions about the intended audience. Popular physics readers are implicitly imagined as being receptive to specialized terminology and conceptual detail, yet resistant to the abstract mathematical frameworks from which these insights originate.

3.3 History of physics

A significant difference between physics textbooks and popular physics books concerns the role of historical context. In physics textbooks, historical background is typically minimized or excluded altogether. Concepts are often presented in a non-chronological order, prioritizing logical coherence and pedagogical progression over historical development. When historical information is included, it is usually confined to brief sidebars, end-of-chapter notes, or isolated sections that are clearly marked as supplementary and optional for the reader.

In contrast, history plays a central role in many popular books on quantum mechanics. The selection of books analyzed in this thesis, though primarily based on popularity rather than on particular sub-genres, demonstrates the prominence of historical narrative across a wide range of popular works. In many cases, substantial portions of these books are devoted to recounting the historical development of quantum mechanics, with detailed discussions of the key figures, discoveries, and debates that have shaped the field. This is to be expected in works such as George Gamow's *Thirty Years that Shook Physics* [29] or Jim Baggott's *The Quantum Story* [47], where history is explicitly foregrounded. However, even in titles where history is not the main advertised focus, a significant amount of space is nonetheless devoted to historical exposition. Some of the books studied in this thesis are entirely about history of physics, for example Kumar's *Quantum*, which goes into impressive historical details [27]. Ananthaswamy's *Through Two Doors at once* is less granular in its recollection of historical facts, but still dedicates most of its pages to the history of the experiments and theories it sets out to discuss [2]. Some other books don't set out to recall the entire history of quantum mechanics, but still use it heavily in the first few chapters of their book, for example chapters 1 and 2 in *The Quantum Universe* by Brian Cox and Jeff Forshaw are entirely dedicated to the history of physics that preceded quantum theory [28]. Approximately the first 20 pages of Raymer's *Quantum Physics: What Everyone Needs to Know* are dedicated to history of physics [32], and so are part 1 of Pagels's *The Cosmic Code* [25] and the chapter 1 to 5 of *The New Quantum Universe* by Tony Hey and Patrick Walters. Part 1 of Greene's *The Elegant Universe* is entirely dedicated to catching up the reader to "the edge of knowledge" [35].

In those books where historical narrative plays a major role, scientific concepts are often introduced in chronological order [27, 2, 40]. Scientists are typically presented in the context of their first major contributions, accompanied by brief historical facts, personal anecdotes, or descriptions of their personalities and social backgrounds. These elements serve to humanize the narrative and offer readers an accessible entry point into complex scientific discussions. As an example, here is how Kumar introduces the figure of Helmholtz:

> "As a teacher, Helmholtz was a severe disappointment. 'It was obvious,' Planck said later, 'that Helmholtz never prepared his lectures properly.' Gustav Kirchhoff, who had also transferred from Heidelberg to become the professor of theoretical physics, was so well prepared that he delivered his lectures 'like a memorized text, dry and monotonous'. Expecting to be inspired, Planck admitted 'that the lectures of these men netted me no perceptible gain'. Seeking to quench his 'thirst for advanced scientific knowledge', he stumbled across the work of Rudolf Clausius, a 56-year-old German physicist at Bonn University" [27].

The central figures in the development of quantum mechanics also serve an important function in framing the philosophical discussions that often accompany popular treatments of quantum theory. The debate between Einstein and Bohr, for instance, represents both a scientific and a philosophical conflict that allows authors to explore foundational issues in a manner accessible to general audiences [2, 27]. Many of these scientists, moreover, were accomplished communicators in their own right [34, 37]. Einstein, in particular, demonstrated a remarkable ability to express complex ideas in vivid and memorable language. His well-known phrases such as "spooky actions at a distance" and "God does not play dice" have become iconic, and their inclusion in popular books further enriches the narrative.

In many cases, historical context serves not merely as a backdrop but as an active narrative device that introduces tension, drama, and ideological contrast within the unfolding story of quantum mechanics. For example, Kumar draws on the history of physics to highlight the conceptual struggles and paradigm shifts that defined the early development of quantum theory [27]. In works that advocate for specific interpretations, such as the many-worlds theory, the historical record is sometimes framed to emphasize interpretive conflicts, casting the many-worlds view as a marginalized or "underdog" perspective in contrast to the more dominant Copenhagen interpretation [28, 38]. This rhetorical framing will be analyzed in further detail in the section devoted to the many-worlds interpretation.

It is difficult to estimate what exact percentage of these books are dedicated to history of physics, because elements like anecdotes from the personal lives of scientists or historical context are often woven into the prose, and there is no clear distinction between paragraphs that are dedicated to history of physics and paragraphs dedicated to theoretical explanations. By interweaving technical discussions with biographical anecdotes and historical events, authors are able to "dilute" abstract or challenging content, rendering it more accessible without diminishing its intellectual integrity. While nearly all of the books examined in this thesis employ this approach to some extent, the previously cited *Through Two Doors at Once* by Ananthaswamy stands out as an especially illustrative example. The most conceptually demanding sections of the book, particularly those explaining the theory behind key experiments, are presented within richly contextualized narratives. Rather than emphasizing the abstract formalism of quantum theory, Ananthaswamy focuses on the experimental dimension of the discipline, framing complex ideas as responses to concrete scientific problems. In doing so, he places theoretical explanation in dialogue with historical context and scientific biography [2].

This narrative strategy offers several pedagogical benefits. It allows readers to engage with the subject matter through human stories, fosters emotional investment, and makes even the more difficult sections of the text feel anchored in lived scientific practice. For readers who may not fully comprehend every technical detail, these stories nonetheless provide an enduring appreciation for the people, conflicts, and historical developments that shaped quantum mechanics.

Among the many techniques available to authors of popular quantum mechanics books, the strategic use of history is arguably the most consistently applied and effective. History of physics is arguably the most effective tool in the books analysed for this thesis, and constitutes the backbone of quantum mechanics communication. Looking at the texts analysed in this thesis, it appears evident that to communicate quantum mechanics to the general audience is to tell the history of quantum mechanics, and the role of history of physics in popularizing quantum mechanics cannot be overstated.

3.4 Metaphors

Analogical reasoning is a hallmark of effective science communication. It allows complex or abstract ideas to be reframed using familiar concepts, making them easier to visualize and mentally manipulate. Metaphors and analogies play a fundamental role that in the understanding of physics. As Ball intelligently writes: "it is the easiest thing in the world for the pedant to say 'Oh, it's not really like that at all.' This isn't my intention. Such elaborately prosaic imagery is often a good place to start the journey, and I will sometimes resort to it myself. Sometimes an imperfect analogy like this is all that can be sensibly expected without engaging in detailed mathematical expositions, and even specialists sometimes have to entertain such pictures if they aren't ready to capitulate to pure abstraction" [39].

Analogies and metaphors are implied not just with the educational goal of making quantum mechanics accessible to laypeople, but also for aesthetic and literary purposes: Hoffmann compares an atomic nucleus to a volcano with a "restless ocean of particles", where an ordinary nucleus is an "extinct volcano" and a radioactive one is an "active one" [41], and this metaphor is not just useful for giving the reader a mental picture of what might be happening in a nucleus, but it also make for memorable and vivid storytelling.

However, "the relationship between quantum theory and metaphor is a particularly problematic one" [19] probably in part due to the inherent abstract difficulty of the subject. In fact, the question of how to "visualize" subatomic particles is one that has been accompanying theoretical physicists from the very origin of quantum theory: Heisenberg himself asks "can one speak of the electron?" in *Physics and Philosophy* [34]. As Leane explains, "when literature and science critics turn to popularization for information, they often appear to forget the status of these books as textual constructions, treating them as straightforward, transparent summaries of what is assumed to be a homogenous and harmonious scientific community. This means that metaphors (and other literary devices) employed by popularizers to achieve particular ends are accepted at face value, rather than interrogated" [19]. Metaphors and analogies are therefore particularly worthy of scrutiny.

Analogies and metaphors are used profusely throughout all books. Only a few examples will be listed:

- Both Gribbin and Kumar use the analogy of a bank teller dispensing money in fixed denominations to help explain Planck's proposal of a quantization of energy. Here is how Kumar explains it: "Guided by his formula, Planck had been forced into slicing up energy E into $h\nu$-sized chunks, where ν is the frequency of the oscillator and h is a constant. $E = h\nu$ would become one of the most famous equations in the whole of science. If, for example, the frequency was 20 and h was 2, then each quantum of energy would have a magnitude of $20 \times 2 = 40$. If the total energy available at this frequency were 3600, then there would be $3600/40 = 90$ quanta to be distributed among the ten oscillators of that frequency. Planck learned from Boltzmann how to determine the most probable distribution of these quanta among the oscillators. He found that his oscillators could only have energies: $0, h, 2h, 3h, 4h \ldots$ all the way up to nh , where n is a whole number. This corresponded to either absorbing or emitting a whole number of 'energy elements' or 'quanta' of size h. It was like a bank cashier able to receive and dispense money only in denominations of £1, £2, £5, £10, £20 and £50" [27].

- The quantum energy levels in atoms are often compared to the normal modes of vibration of a violin string or a sound wave in an organ pipe, where wavelengths must "fit" [1, 28, 40]. This is an excellent analogy because the physics behind vibrating strings and subatomic particles is very similar (namely, wave mechanics) but it also could produce confusion in a reader that is not familiar at all with the subject. This analogy with guitar strings is still more effective than Hoffmann's explanation, where Bohr's rules for electron orbits are likened to trolley tracks where only certain lengths (integral multiples of circumference, or half, etc.) are permitted for stability [41].

- Similarly, interference patterns are often explained using water waves striking a barrier with two slits, where outgoing circular waves overlap, and peaks reinforce while troughs cancel [2, 35, 27].
- Quantum vacuum fluctuations are often explained as the possibility to "borrow energy" from the vacuum as long as "it is paid back fast enough", likening it to a bank loan [33] or an airplane ticket [35].
- To visualize the extra dimensions in string theory, Cox and Forshaw offer the "tangible example of the garden hose" [28], where an ant on the hose perceives only one dimension, while from a distance, the hose appears one-dimensional, masking its curled up dimension. This metaphor is also employed by Greene [35].
- Pagels compares the eightfold-way classification of hadrons, which only combine into specific families, to the pieces of a Tinker Toy set, which can only be put together into certain combinations [25].
- For Hey and Walters, quantum paths (snapshots of electron position over time) are "very jiggly no matter what magnification", exhibiting fractal properties by "looking the same at all length scales", similar to measuring the coastline of Great Britain [36].

A lot of analogies and metaphors are anthropomorphic in nature. For example, Pagels asks us to "imagine that quantum reality is like a sealed box out of which we receive messages" [25]. In a discussion about the Higgs mechanism, Baggott writes: "imagine a cocktail party in which a room is uniformly populated with physicists quietly drinking cocktails and chatting among themselves. This is equivalent to the vacuum containing the Higgs field. A noted celebrity physicist enters the room and causes something of a stir. This is the massless Yang–Mills boson. The physicists gravitate in the direction of the celebrity [...] and, before too long, a throng has gathered around her which slows down her progress as she crosses the room" [47]. Authors sometimes say that a quantum particle "chooses" which quantum state to collapse its wavefunction into [38, 35]. Leane notices frequent use of the word "knowing" referred to electrons [19]. Mr. Tompkins literally becomes an electron in one of the chapters [30], and Gilmore's Alice has the possibility to visit Quantumland and to talk directly to particles [33].

Leane builds on Beer's observation that the efficacy of a metaphor rests upon the context in which it is used, and writes "although phrases such as "the electron knows" or "makes up his mind" [...] could potentially impart a sense of consciousness to the electron [...] the context of the metaphor in each case does not encourage such an interpretation" [19]. The efficacy of the metaphor is, therefore, highly dependent on the context.

Anthropomorphic metaphors therefore shouldn't be considered inherently misleading, and there are a lot of positive examples of them. One of these is Gribbin, who uses an analogy with concert-goers to explain the difference between bosons and fermions, writing

> "The subtleties need not concern us now, but the distinction between fermions and bosons is an important one that can be easily understood. Some years ago, I went to see a play starring the comedian Spike Milligan. Just before the curtain went up, the great man himself appeared on stage and took a baleful look at the handful of empty seats in the most expensive part of the auditorium, near the stage. "They'll never find anyone to buy these now", he said, "you might as well all move up here where I can see you". The audience did as he suggested-everybody moved forward so that all the seats near the stage were full, while the handful of empty seats was left at the back. We were acting like nice, well-behaved fermions, each person occupying just one seat (one quantum state) and filling up the seats from the most desirable "ground state", by the stage, outward. Contrast this with the audience at a recent Bruce Springsteen concert I attended. There, every seat was full, but there was a small gap between the front row of seats and the stage. As the stage lights went up and the band hit the first chord of "Born to Run" the entire audience surged forward out of their seats and crammed up against the stage. All of the "particles" crammed into the same "energy state" indistinguishably-and that is the difference between fermions and bosons. Fermions obey the exclusion principle, bosons do not" [1].

This is a very good metaphor to explain the difference between the two particles, and readers are likely not walking away from this book with the idea that fermions and bosons have human-like characteristics beyond the ones illustrated in this paragraph.

However, "a context that is likely to activate the "potential significations" of anthropomorphic metaphor is one in which the consequences of the theory for humanity's image of itself are brought to the fore" [19]. In the context of an interpretation of quantum mechanics that brings human consciousness to the forefront of what is explained (such as the "consciousness causes collapse" interpretation), anthropomorphic metaphors are more likely to be misunderstood. As an example of possibly misleading language, Leane criticises Gary Zukav's usage of "slippery metaphors" [19] in his book *The Dancing Wu Li Masters*, which will be discussed further in the final section of this thesis.

Analogies and metaphors are vital to reader comprehension, helping bridge the conceptual gap between formal derivation and intuitive grasp. The strength of such analogies lies in their ability to offer readers a cognitive foothold, even if they cannot follow the formal derivation. The context of their usage, however, is very important and should be considered when choosing which metaphor to adopt.

3.5 Narratives

The ability to weave historical developments and scientific theories into compelling narratives is a hallmark of effective science communication. Within the corpus of popular quantum mechanics books analyzed in this thesis, narrative structure plays a central role in guiding readers through conceptually difficult material and enhancing engagement. By casting scientific progress as a story of individuals, conflicts, and intellectual discovery, authors provide readers with familiar rhetorical structures that render abstract concepts more relatable and memorable.

A particularly prominent narrative is the debate between Einstein and Bohr. This well-known intellectual rivalry is not only frequently cited but often elevated to the status of a dramatic through line. Books such as *The Quantum Story* [47], *In Search of Schrödinger's Cat* [1], and *The New Quantum Universe* [36] recount their philosophical disagreements over the interpretation of quantum mechanics, with Kumar's *Quantum: Einstein, Bohr and the Great Debate about the Nature of Reality* organizing the entire book around this central conflict [27]. This example illustrates how narrative framing can turn abstract theoretical debates into emotionally and intellectually resonant storylines, drawing readers into the history and stakes of the subject matter.

Since narrative is an essential component of nearly all the books surveyed, it is instructive to examine one particular narrative pattern in greater detail: the presentation of the many-worlds interpretation as an underdog.

3.5.1 Many-worlds as the underdog

Physicists using their popular quantum mechanics books to argue in favor of their chosen interpretation of quantum mechanics is not something that only happens with the many-worlds interpretation. Carlo Rovelli is one of the inventors of loop quantum gravity, and he openly defends this interpretation in his popular physics books [42, 48]. For example, in *Seven Brief Lessons of Physics*, Rovelli writes:

> "The central result of loop quantum gravity is indeed that space is not continuous, that it is not infinitely divisible but made up of grains or 'atoms of space'. These are extremely minute: a billion billion times smaller than the smallest atomic nuclei. The theory describes these 'atoms of space' in

mathematical form, and provides equations which determine their evolution. They are called 'loops', or rings, because they are linked to each other, forming a network of relations which weaves the texture of space, like the rings of a finely woven immense chain mail. Where are these quanta of space? Nowhere. They are not in a space because they are themselves the space. Space is created by the linking of these individual quanta of gravity. Once again the world seems to be less about objects than about interactive relationships. But it's the second consequence of the theory that is the most extreme. Just as the idea of a continuous space that contains things disappears, so the idea of an elementary and primal 'time' flowing regardless of things also vanishes. The equations describing grains of space and matter no longer contain the variable 'time'. This doesn't mean that everything is stationary and unchanging. On the contrary, it means that change is ubiquitous – but elementary processes cannot be ordered in a common succession of 'instants'. At the minute scale of the grains of space, the dance of nature does not take place to the rhythm of the baton of a single orchestral conductor, at a single tempo: each process dances independently of its neighbours, to its own rhythm. The passage of time is internal to the world, is born in the world itself in the relationship between quantum events that comprise the world and are themselves the source of time" [42].

In other writings he goes on to explain this theory more in detail, taking up at least the last third of his other book on quantum mechanics, *Helgoland* [48].

However, the many-worlds interpretation of quantum mechanics is espoused by many quantum mechanics popularizers, both experts and not. Out of the 26 books analysed in this thesis, at least 15 mention and discuss the many-worlds interpretation [26, 49, 2, 47, 28, 50, 25, 27, 38, 39, 32, 33, 36, 40, 31], and a lot of them are openly in support of it. For comparison, the consciousness-causes-collapse interpretation is only mentioned in 9 books, and only seriously considered in Gary Zukav's work [51]. The many-worlds interpretation is somewhat overrepresented, so to speak, and therefore deserving of further discussion.

The many-worlds interpretation, originally proposed by Hugh Everett in 1957 under the title "theory of the universal wavefunction" [52], has occupied a marginal position in mainstream quantum physics discourse for decades. It only began to gain wider public recognition with the publication of David Deutsch's *The Fabric of Reality* [50] in 1997, which championed the interpretation and framed it as a paradigm-shifting alternative to the prevailing Copenhagen view. Deutsch dedicates his book "to the memory of Karl Popper, Hugh Everett and Alan Turing, and to Richard Dawkins" adding "This book takes their ideas seriously". He explicitly argues that the existence of the multiverse is an "inescapable conclusion", and that quantum theory "describes a multiverse" [50].

According to the many-worlds perspective, the wavefunction is real and universal, and there is no collapse upon measurement. Instead, every possible outcome of a quantum measurement occurs in a separate, parallel world. To borrow a metaphor from Everett himself, quoted in Ananthaswamy's book, "one can imagine an intelligent amoeba with a good memory. As time progresses the amoeba is constantly splitting, each time the resulting amoebas having the same memories as the parent. Our amoeba hence does not have a life line, but a life tree. The question of the identity or non identity of two amoebas at a later time is somewhat vague. At any time we can consider two of them, and they will possess common memories up to a point (common parent) after which they will diverge according to their separate lives thereafter [...] The same is true if one accepts the hypothesis of the universal wavefunction. Each time an individual splits he is unaware of it, and any single individual is at all times unaware of his 'other selves' with which he has no interaction from the time of splitting" [2]. While this interpretation remains controversial among physicists, it is nonetheless endorsed by some notable figures, including Brian Cox [28].

As Dihal observes, Deutsch's rhetorical strategy relies heavily on the construction of a conflict narrative: the many-worlds interpretation is framed not as one among several valid perspectives, but as a revolutionary idea struggling for recognition in the face of a complacent orthodoxy. "The focus usually lies on the Copenhagen interpretation and the many-worlds interpretation. Popularizers tend to express a clear preference for an interpretation, usually one of these two, which leads to two different kinds of scientific stories told in popularizations: stories of conflict and stories of agreement." [13]. They go on to note that "Deutsch suggests that he is giving his readers the possibility of engaging with more complex concepts than the average quantum physicist can handle. He does not mention the Copenhagen interpretation until page 327 [...] To a reader introduced to quantum theory in this way, it would be difficult to imagine how it is possible to work with quantum physics at all without applying the many-worlds interpretation. Deutsch's explanation of the Copenhagen interpretation reinforces this idea, as he presents it as outdated" [13].

Other authors also use an underdog narrative, for example, by telling the reader about the initial dismissal that Everett had to face. Kumar writes "Everett published his alternative in July 1957 with an accompanying note from his supervisor, the distinguished Princeton physicist John Wheeler. It was his very first paper and it went virtually unnoticed for more than a decade. By then, disillusioned by the lack of interest, Everett had already left academia and was working for the Pentagon, applying game theory to strategic war planning." and later in the book says "there were unbelievers prepared to challenge the Copenhagen orthodoxy, one of them was Hugh Everett III" [27] framing Everett as a clear underdog. Ananthaswamy, Hey and Walters, Pagels and Baggott also mention this initial dismissal that Everett had to face, even if they don't express as clear a preference for any specific interpretations [2, 36, 25, 47]. Many frame Everett's story as one of institutional neglect, of a man still struggling for recognition. Authors point out that Everett's doctoral thesis was "received rather coldly in Copenhagen" [2] or "largely ignored at the time" [39]. Some authors emphasize dismissal from key figures in the life of Everett, like how his own PhD supervisor John Wheeler initially found the first draft of Everett's thesis "barely comprehensible" [36] or how theoretical physicist Bryce DeWitt, editor of the issue of Reviews of Modern Physics in which Everett's shortened thesis had appeared, was initially "stunned" and "shocked" by the concept of observer splitting, stating "I simply do not branch" [47]. Orzel (through his dog Emmy) also expresses a clear distaste for the Copenhagen interpretation, and a subtle preference for the many-worlds interpretation [38]. Gribbin cites the Copenhagen interpretation as the most widely supported, "even if it's not his personal favorite" [1]. Cox and Forshaw don't write a conflict narrative per se, but they do express a clear preference for the Everett interpretation [28].

In an underdog narrative, a worthy protagonist has to start off as an outlier or outcast. This means that the lack of support from the scientific community for the Everett interpretation, which should deter people from believing in it, at least until more scientific evidence is collected to support it, instead becomes a positive thing. Dihal also notices that "when reading either of Rae's popularizations, or McEvoy and Zarate, the reader might instead be led to support the Copenhagen interpretation" [13]. meaning that readers of different popular quantum mechanics books might come away with substantially different understanding of the state of modern physics, depending on which interpretation of quantum mechanics the author supports.

In sum, the many-worlds interpretation functions as a powerful narrative device as much as a scientific stance. Framing it as an embattled outsider energizes the story, but it also reshapes readers' sense of consensus and can blur the line between open debate and established result. For some audiences this raises curiosity and lowers resistance; for others it steepens the conceptual path by front-loading philosophical commitment over methodological context. What matters, then, is not only which interpretation is endorsed, but how that endorsement is staged, since narrative choice directly affects cognitive load and expectations.

3.6 The "hill"

To better conceptualize the cognitive and narrative experience of reading a popular quantum mechanics book, it is helpful to introduce a guiding metaphor. Imagine the reader's journey through the book as a walk along a path. This path occasionally ascends: it begins gently in places where the prose is clear, intuitive, and accessible, then steepens in sections that present more abstract ideas, unfamiliar terminology, or conceptually difficult content. In this metaphor, the increase in cognitive demand can be likened to walking uphill. The steeper the incline, the more the reader is required to focus, re-read, and actively engage with the material. These metaphorical "hills" represent the moments in the text where the reader encounters intellectual resistance, but also where some of the most meaningful engagement with the material can occur.

The presence of such hills is not a flaw in the structure of a popular science book. On the contrary, they are not only expected but essential. Any explanation of a complex scientific phenomenon, particularly within a field as abstract and counterintuitive as quantum mechanics, will necessarily contain sections that are more challenging than others. These moments of difficulty are an inherent feature of scientific communication. Regardless of the skill of the writer or the assumed background of the reader, there will always be sections that demand a greater investment of attention and mental energy.

What matters is not whether these moments of difficulty exist, but how they are handled. The task of the science communicator is not to eliminate complexity, but to guide the reader up the hill in a way that is as smooth and engaging as possible. The communicator acts as a kind of mountain guide, pacing the climb, providing support, and occasionally offering an easier path without abandoning the goal of intellectual ascent. In many cases, it is precisely these more demanding sections that readers find most satisfying and memorable. They are the moments when the reader feels they are gaining a genuine insight into a world that is otherwise opaque and inaccessible. The capacity of the communicator to instill in their readers a sense of awe and wonder is a key skill for an effective communication not just of quantum mechanics, but of science as a whole. A sense of wonder is an important component of a memorable and beautiful book, especially around a topic as mysterious as quantum mechanics. The moments of intellectual difficulty are the more challenging ones, where the connection with the audience might feel more tenuous, but also the ones where that connection can be strengthened, and readers can gain the sought-after insight that they bought the books for. In this sense, the hill is not an obstacle to be removed, but a meaningful feature of the landscape.

This thesis argues that the "hill" metaphor captures a central challenge of popular quantum mechanics writing. These are delicate narrative moments: they can either deepen the reader's engagement or risk losing their attention altogether. Understanding how these difficult moments are structured, prepared for, and navigated is crucial for both analyzing existing works and guiding future science communication practice.

The remainder of this chapter will examine this challenge more closely. First, a number of representative examples will be presented, illustrating how these hills manifest in specific texts. Second, I will analyze some of the rhetorical and pedagogical strategies used by authors to mitigate their impact. Finally, the chapter will consider strategies that appear to hinder rather than help, and which future communicators should therefore approach with caution.

3.6.1 Examples of "hills" in popular quantum mechanics books

Capturing the nuanced progression of cognitive demand across chapters in a popular science book is inherently difficult without presenting extended excerpts from the texts themselves. Nonetheless, several representative cases can be identified that illustrate how moments of increased complexity (the metaphorical "hills") are constructed and encountered in popular quantum mechanics literature.

- Chapter 3 of *Quantum Theory: A Very Short Introduction* marks a clear shift in tone and complexity. Here, the author moves from the descriptive and historical to the philosophical, exploring various interpretations of quantum mechanics, including the measurement problem and debates about determinism and reality. These topics are abstract, conceptually layered, and often counterintuitive. While still presented in accessible language, this section demands greater intellectual engagement from the reader and may challenge those without prior exposure to foundational physics or philosophy of science. It exemplifies a moment in which the cognitive terrain begins to incline more sharply.

- *The Quantum Universe*, written by Brian Cox and Jeff Forshaw, is arguably among the more demanding texts examined in this thesis. The book hinges on an extended metaphor involving the behavior of clocks to illustrate complex mathematical ideas such as trigonometry and probability amplitudes. This metaphor is designed to circumvent the need for direct mathematical exposition, yet the conceptual content remains dense. Chapter 6, in particular, presents a sustained engagement with abstraction that is likely to test the reader's attention and interpretive skills. For motivated readers, the experience can be intellectually satisfying, but for others it may mark a moment where comprehension falters. This chapter stands as a particularly steep "hill" in the narrative.

- In Ananthaswamy's *Through Two Doors at Once*, the prose is fluid and the overall structure is reader-friendly, making the book suitable for audiences new to quantum theory. Nevertheless, Chapter 5 introduces a noticeable shift in tone and content. Here, the discussion begins to delve deeper into the implications of the double-slit experiment and issues of nonlocality, introducing technical terms and conceptual puzzles that may be unfamiliar. While the incline is not severe, it does require readers to recalibrate their attention and engage with more demanding material. This gradual increase in difficulty is characteristic of effective science communication, where more abstract material is introduced only after a strong narrative foundation has been laid.

Each of these examples highlights a moment where the explanatory tone shifts, often subtly, toward greater abstraction or technical complexity. These shifts are rarely abrupt but are nonetheless perceptible to the attentive reader. They can serve as useful case studies in how popular science writers structure cognitive pacing, building up to more difficult content without alienating their audience. The examples discussed here will be explored in greater detail in Chapter 4, which examines the structural, stylistic, and pedagogical choices that characterize these texts.

3.6.2 Strategies for managing the "hill"

The books analyzed in this thesis encounter and respond to "hills" of varying steepness. These more intellectually challenging sections are inevitable in the explanation of complex phenomena, particularly in the context of quantum mechanics. While no single strategy guarantees complete clarity or comprehension for all readers, a number of recurring rhetorical techniques can be observed in successful popular science writing. These strategies aim to acknowledge the difficulty, reduce cognitive overload, and maintain reader engagement at critical moments.

Reassuring the audience

Sometimes, a simple acknowledgement that the material is difficult, combined with reassurance about its purpose or payoff, is enough to sustain the reader's motivation. These brief interjections help preserve the trust between author and reader and act as invitations to persevere through the more demanding passages.

- In a similar move, Polkinghorne offers a gentle warning prior to introducing a mathematical concept: "Warning to the reader: This section includes some simple mathematical ideas that are well worth the effort to acquire, but whose digestion will require some concentration. This is the only section in the main text to risk a glancing encounter with mathematics. I regret that it cannot help being somewhat hard-going for the non-mathematician" [40].
- before diving into string theory, Brian Green employs a bit of humor while reassuring his audience, saying "Don't worry. The really hard work has already been done by string theorists and we will content ourselves here with explaining their results".
- Chad Orzel promises his fictional dog Emmy that they will "go over the book together, and if there are places where you think I've left stuff out, we can talk about them, and I'll put your comments in the book" implicitly reassuring his audience too that the book is accessible.

These acknowledgements signal to readers that struggle is anticipated and acceptable, and that the challenge will be met with narrative support and conceptual payoff.

"The gist of it"

A widely used technique in popular science writing involves summarizing mathematical or abstract concepts in plain language. These paraphrased explanations serve to preserve the essence of the scientific idea for readers who may not follow the formalism.

This technique is easily recognizable, often introduced by expressions like "all that matters for now is..." or "the idea behind it is..." and similar phrases. Cox and Forshaw, for example, after using a rather abstract analogy between water waves and electrons, write: "All that matters for the moment is that we recognize the analogy with water waves, and the notion that the electron is described at any instant by a wave that propagates and interferes like water waves do” [28].

In many occasions, "the gist of it" is simply an efficient visual metaphor, and the role of metaphors and analogies has been discussed more in depth in a previous section. It just felt important to further highlight this as a technique to guide the reader through a particularly challenging idea, because it is widely used and very efficient.

Humor

Humor, when used effectively, can provide a moment of levity and defuse the tension associated with particularly abstract material. It also helps humanize the author and re-establish a sense of shared experience. It is somewhat difficult to spot and describe, as definitions of it can vary considerably. For the sake of this thesis, any creative choice that undermines the reputation of physics as a very serious subject, so to speak. Let us list some examples:

- The entire premise of Orzel's book *How to explain quantum physics to your dog* is entertaining and unserious, and the tone of the book matches the expectations set by its title. One of many examples of its whimsical tone is the scene where Emmy (the titular dog) proposes a term for a new quantum particle: the "squirunny" (squirrel-bunny) [38].

- George Gamow's *Mr. Tompkins' Adventures* has a whimsical tone and an absurdist sense of humor, creating memorable scenes such as Mr. Tompkins comically misunderstanding "Hamiltonian" as a "famous hunter", and Mr. Tompkins comically trying to explain "scrambled eggs" and "breakfast" to an intrigued electron [30]. Similar considerations can be made of *Alice in Quantumland*, which takes inspiration from the famous Lewis Carroll book to illustrate quantum mechanics [33]. *Mr. Tompkins' Adventures*, *Alice in Quantumland* and *How to explain quantum physics to your dog* are not specifically written for children or young adults, but their lighthearted tone makes them excellent for these audiences too.

- Feynman's charisma and sense of humor shines through the pages of *Six Easy Pieces*, with analogies such as the "amusing story of Dennis the Menace who is always mischievously hiding his toy building blocks from his mother" in Chapter 4 [37].

- Heisenberg's *Physics and Philosophy* contains some occasional irony. For example, Heisenberg recalls the anecdote: "In discussions about the limitations of concepts, Bohr likes to tell the following story: "A little boy goes into a grocer's shop with a penny in his hand and asks: 'Could I have a penny's worth of mixed sweets? The grocer takes two sweets and hands them to the boy saying:" Here you have two sweets. You can do the mixing yourself" [34].

- Rovelli's *Seven Brief Lessons on Physics*, which contains the sentence "The force that 'glues' quarks inside protons and neutrons is generated by particles that physicists, with little sense of the ridiculous, call 'gluons'".

Many books break their more heady paragraphs up with funny anecdotes about the lives of physicists. Ananthaswamy recalls how at a lecture, Feynman observed: "It's odd, but in the infrequent occasions when I have been called upon in a formal place to play the bongo drums, the introducer never seems to find it necessary to mention that I also do theoretical physics!" [2]. Greene recalls that upon the discovery of the muon, which had no apparent purpose in the cosmic order, Rabi famously asked, "Who ordered that?" [35]. Hey and Walters recall "an amusing story" told by Heisenberg about Dirac: "The two of them were travelling to Japan from the USA by boat and Heisenberg liked to join in the social activities that went on in the evenings. At a dance one night, Heisenberg was enjoying himself dancing and Dirac, as usual, was sitting watching. As Heisenberg came back to his chair after a dance Dirac asked him 'Why do you dance?' Heisenberg replied 'Well, when there are some nice girls it is a pleasure to dance'. Dirac thought about this for a while. After about five minutes, he said 'Heisenberg, how do you know beforehand that the girls are nice?'" [36]. Finally, Ball retells the famous joke where Heisenberg is pulled over for speeding, the police officer asks him, 'Do you know how fast you were going?' 'No,' and Heisenberg replies, 'but we know exactly where we are!'" Ball uses this joke as an example of common misunderstandings of the uncertainty principle, and calls it "half-baked" [39].

While not all authors employ humor, it remains a powerful tool for maintaining reader engagement.

Modern physics as a crutch

Another effective strategy is to ground the discussion in early twentieth-century experiments from modern physics. These experiments, such as blackbody radiation or the photoelectric effect, lend themselves more readily to intuitive interpretation than later quantum phenomena like entanglement or field quantization. As a result, they are often used as narrative starting points for introducing core quantum ideas.

For instance, the wave-particle duality of light is frequently introduced through the photoelectric effect [40, 2, 27]. The concept of quantization is often framed through the early work of Planck, presented not only as a scientific turning point but also as a biographical one. This biographical storytelling can be seen in books by Cox and Forshaw, Kumar, and Gribbin, who narrate the early challenges and breakthroughs in

Planck's career to illustrate how quantization emerged as a solution to a well-defined empirical puzzle [28, 27, 1].

These foundational experiments serve as a conceptual bridge for the reader. They offer a more tangible context before the discussion moves into the more abstract theoretical terrain characteristic of later quantum mechanics. By anchoring the "hill" in historically and experimentally grounded material, authors create a gentler gradient for readers to climb.

Anecdotes: the example of Schrödinger's cat

Since the role of anecdotes is so important in popular quantum mechanics books, there would be simply too many to analyze. It's useful to focus on one of the most widely used examples. Let us focus on how Schrödinger's cat is used in popular quantum mechanics books.

In 1935, Schrödinger presented his now-famous thought experiment to underscore what he regarded as fundamental inconsistencies within the Copenhagen interpretation. In his essay *The Present Situation in Quantum Mechanics*, he proposed:

> "One can contrive even completely burlesque [farcical] cases. A cat is put in a steel chamber along with the following infernal device (which must be secured against direct interference by the cat): in a Geiger counter, there is a tiny amount of radioactive substance, so tiny that in the course of an hour one of the atoms will perhaps decay, but also, with equal probability, that none of them will; if it does happen, the counter tube will discharge and through a relay release a hammer that will shatter a small flask of hydrocyanic acid. If one has left this entire system to itself for an hour, one would tell oneself that the cat is still alive if no atom has decayed in the meantime. Even a single atomic decay would have poisoned it. The psi function of the entire system would express this by having in it the living and dead cat (pardon the expression) mixed or spread out in equal parts. It is typical of these cases that an indeterminacy originally restricted to the atomic domain turns into a sensually observable [macroscopic] indeterminacy, which can then be resolved by direct observation. This prevents us from so naïvely accepting a "blurred model" as representative of reality. Per se, it would not embody anything unclear or contradictory. There is a difference between a shaky or out-of-focus photograph and a snapshot of clouds and fog banks" [53].

With this thought experiment, Schrödinger transformed a quantum-level indeterminacy into a macroscopic paradox. If the system is left undisturbed for an hour, quantum mechanics predicts that the cat's wavefunction exists as a superposition of "alive" and "dead" states until an observation is made. Schrödinger intended this scenario to expose the uncomfortable consequences of applying quantum superposition beyond the microscopic realm. He emphasized that a "blurred model" justified at the atomic scale becomes intolerable and nonsensical when transposed onto everyday objects. In his view, the thought experiment intentionally strikes one as absurd, because the absurdity reflects a deeper flaw in the theoretical framework that predicts it. As Ryan says: "Schrödinger does not represent his own position but rather adopts the point of view of what has come to be known as the Copenhagen interpretation in order to expose its absurdity" [54].

It's not obvious when Schrödinger's cat became a staple of quantum mechanics popularizations. The 1965 series *Mr. Tompkins* by George Gamow, for example, doesn't mention it [30], and neither does Richard Feynman's very influential *Six Easy Pieces* [37]. On the other hand, John Gribbin's *In search of Schrödinger's cat*, published in 1984, assumes that the reader is familiar with it, and uses it as the through line of the book and as its main selling point [1]. The cat is often used as a teaser: the paradox is introduced early in the book, but not explained until much further along [13]. This might be because the emotional investment of finding out whether or not a beloved animal dies is a great cliffhanger and provides a natural narrative structure to the book. Gribbin and Orzel both use this trick [38, 1]. Rae on the other hand, does not hint at the cat before discussing it, about halfway through the book [26]. Kumar talks about it only at page 305 out of 432, and does not hint about it before [27].

Schrödinger's cat is a self contained anecdote that can be understood by anyone, without the need for calculations or deep knowledge about physics, and it also was written by one of the biggest minds behind quantum mechanics. Einstein himself praised his colleague for the efficacy of the thought experiment [47]. It's a very attention grabbing idea, with both mystery and violent imagery. It also comes with its own cliffhanger, because the original formulation of the paradox doesn't have a conclusion. Marie-Laure Ryan says that "to turn this incomplete, embryonic narrativity into a story worth telling for its own sake, to make it in other words more than a parable entirely subordinated to a particular point, we will need the following improvements: (1) Better individuation of the characters, so as to engage the imagination; (2) Better motivation of the character's actions, to make these actions understandable; (3) An outcome that brings a genuine change of state; (4) Better management of the disclosure of information, so as to create in the reader a desire to know what will happen next. These needs in turn lead to four main strategies for moving from the parable to stories with greater narrativity: (1) turn the cat into a character; (2) turn the performance of the experiment into an event; (3) create suspense by making the outcome uncertain; and (4) use the story as a pretext for reflections on the problem of knowledge" [54].

The paradox of Schrödinger's cat is presented in a lot of popularizations of quantum mechanics [40, 26, 49, 1, 25, 28, 38]. The popularity of the paradox is somewhat self-perpetuating: when authors assume that the reader is familiar with it, it will create curiosity in those readers that haven't heard about it before. Brian Cox and Jeff Forshaw only hint at the paradox in the introduction of their book, when they talk about all the fascinating and strange phenomena of the quantum world, and mention "particles that are in two places at once" and "cats that are both dead and alive" [28]. Other authors rely more heavily on the paradox to draw the reader in, like in John Gribbin's *In Search of Schrödinger's cat*, where it becomes the throughline of the entire book: the cat is teased in the introduction of the book, but the paradox isn't explained until chapter 13, very far into the book [1].

Egil Asprem writes: "Schrödinger's poor cat has gone from servicing a pedantic point about problems in the Copenhagen interpretation, to becoming a catchy emblem for 'weird new science'" [55]. The paradox is great at introducing the counterintuitive nature of quantum mechanics: many books use the paradox as a jumping point to discuss various possible interpretations of quantum mechanics. Some of these are:

1. The split-reality interpretation. In this case, Schrödinger's thought-experiment illustrates the absurdity of trying to scale up a quantum phenomenon. "Translated into narrative terms, this view could produce stories exhibiting what Thomas Pavel calls a "split ontology": a narrative universe made of two domains that obey different rules, such as the sacred and the profane, or the world of everyday life and the world of the supernatural" [54].

2. The Copenhagen interpretation. As we've briefly discussed before, it doesn't make sense to ask which state the cat is in before its state has been measured, and its wavefunction has collapsed. Ryan draws a parallel between this interpretation and the work of Hayden White, saying "just as the act of observation "causes" the cat to be dead or alive, the historian who emplots historical events according to a certain narrative pattern imposes upon reality a determinate form that is fundamentally alien to it" [54].

3. The Hidden Variable Interpretation, also known as Bohmian mechanics, which will be left out of this thesis, because it is very interesting from the physics point of view, but popularizers rarely adopt it as their preferred interpretation.

4. The many-worlds interpretation of quantum mechanics, formulated by Hugh Everett and popularized by David Deutsch (whose book *The Fabric of Reality*, interestingly, doesn't mention the cat paradox [50]). This interpretation states that the wavefunction doesn't collapse, because all possibilities are realized simultaneously. This interpretation is quite talked in popular physics books and it will be discussed further in its own chapter.

5. Conscious Collapse Theory, which also will be left out of this thesis, because it's rarely preferred by popularizers.

The narratives that authors decide to use have a huge influence on which parts of physics they go on to talk about. For example, a lot of authors don't talk about

Schrödinger's equation, but they do mention Schrödinger's cat. Therefore, popular readers of quantum mechanics will walk away with a different idea associated to the name of Schrödinger than physics students [13].

Taken together, these examples show that every popular quantum mechanics book must contend with its own "hills." The ways in which authors prepare readers for difficulty, through reassurance, summary, humor, historical framing, or narrative devices like Schrödinger's cat, shape not only comprehension but also the overall reading experience. The hill, then, is not simply an obstacle but a structural feature of science communication: it is where the balance between clarity and complexity is negotiated, and where readers either stumble or gain their deepest insights. Recognizing how these challenges are constructed and managed provides a lens for comparing different works and for understanding the broader cultural role of popular quantum mechanics writing.

Chapter 4

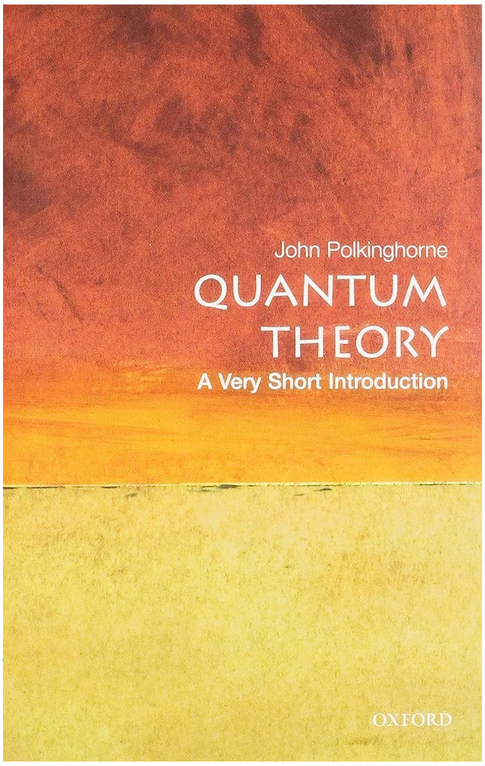
Case studies in popular quantum mechanics

Some of the books analysed in this thesis are of particular interest, and will be discussed more in detail in this chapter. These titles have been chosen because they distinguish themselves for commercial success, fame and influence, and together they showcase a wide array of strategies for explaining quantum theory. The selection balances author background (theorists, experimentalists, science writers), temporal spread (classics to recent works), and mode of exposition (history-led, lecture-derived, interview-rich narrative, highly abstract but non-mathematical, and ultra-concise formats). These books have demonstrably shaped public conversations about quantum mechanics and have also influenced other popularizers, syllabi, and media coverage; they therefore serve as representative exemplars for a closer, qualitative analysis.

4.1 *Quantum Theory: A Very Short Introduction* by John Polkinghorne

Polkinghorne's book is part of the *Very Short Introductions* series by Oxford University Press. It was chosen for closer analysis to test the upper limit of what can be done in a shorter book (about 150 pages) without equations. It exemplifies careful pacing, lucid prose, and concept-first explanations that still reach deep issues (measurement, decoherence, interpretations). As such, it's a benchmark for brevity with substance.

Since the book is shorter, it has to dive into the beginning of quantum theory right away. Already the first chapter *classical cracks* gives the reader some not-so-banal information, like the ultraviolet catastrophe or the photoelectric effect. These parts are relatively easy to understand (especially compared to other parts of quantum theory) but Polkinghorne still makes extra sure to guide his reader at each step, making the "hill" very gentle, with lots of anecdotes and historical context.



Here, Polkinghorne is talking about the double slit experiment:

> "The phenomenon is a neat example of electron wave/particle duality. Electrons arriving one by one is particlelike behaviour; the resulting collective interference pattern is wavelike behaviour. But there is something much more interesting than that to be said. We can probe a little deeper into what is going on by asking the question, When an indivisible single electron is traversing the apparatus, through which slit does it pass in order to get to the detector screen? Let us suppose that it went through the top slit, A. If that were the case, the lower slit B was really irrelevant and it might just as well have been temporarily closed up. But, with only A open, the electron would not be most likely to arrive at the midpoint of the far screen, but instead it would be most likely to end up at the point opposite A. Since this is not the case, we conclude that the electron could not have gone through A. Standing the argument on its head, we conclude that the electron could not have gone through B either. What then was happening? That great and good man, Sherlock Holmes, was fond of saying that when you have eliminated the impossible, whatever remains must have been the case, however improbable it may seem to be. Applying this Holmesian principle leads us to the conclusion that the indivisible electron went through both slits. In terms

> of classical intuition this is a nonsense conclusion. In terms of quantum theory's superposition principle, however, it makes perfect sense. The state of motion of the electron was the addition of the states (going through A) and (going through B)" [40].

I find this explanation very good and easy to understand, and I want to elevate it as an example of good quantum mechanics communication.

In chapter 2 *The light dawns* the path begins to steepen. Polkinghorne explains vector spaces, and here is an example of a paragraph:

> "Sometimes an operator acting on a vector does not change that vector's direction. An example would be a rotation about the vertical axis, which leaves a vertical vector completely unchanged. Another example would be the operation of stretching in the vertical direction. This would not change a vertical vector's direction, but it would change its length. If the stretch has a doubling effect, the length of the vertical vector gets multiplied by 2. In more general terms, we say that if an operator O turns a particular vector v into a multiple λ of itself, then v is an eigenvector of O with eigenvalue λ. The essential idea is that eigenvalues (λ) give a mathematical way of associating numbers with a particular operator (O) and a particular state (v). The general principles of quantum theory include the bold requirement that an eigenvector (also called an eigenstate) will correspond physically to a state in which measuring the observable quantity O will with certainty give the result λ" [40].

Chapter 3 *Darkening perplexities* dives deeper into the philosophy of quantum mechanics, explains some of the interpretations and the problem of measurement. Polkinghorne doesn't use any mathematics for this, and his prose is a good example of how deep a quantum mechanics explanation can go without having to use mathematics. An example quote:

> "It turns out that the consequence of this virtually omnipresent background radiation is to affect the phases of the relevant probability amplitudes. Taking into account this so-called 'phase randomization' can, in certain cases, have the effect of almost entirely washing out the cross terms in quantum probability calculations. (Crudely speaking, it averages about as many pluses as minuses, giving a result near zero.) All this can occur with quite astonishing rapidity. The phenomenon is called 'decoherence'. Decoherence has been hailed by some as providing the clue by which to understand how microscopic quantum phenomena and macroscopic classical phenomena are related to each other. Unfortunately this is only a half-truth. It can serve to make

> some quantum probabilities look more like classical probabilities, but it does not make them the same. There still remains the central perplexity of what is called 'the measurement problem'" [40].

Chapter 4 *Further developments* is less dense and more lighthearted, because it's mostly dedicated to quantum phenomena that have more practical applications, like quantum tunnelling or band structures. He also talks about delayed choice experiments, the EPR paradox and Bell's theorem. These are probably the most abstract topics in the whole book, and Polkinghorne's prose takes the reader surprisingly far even without any abstraction.

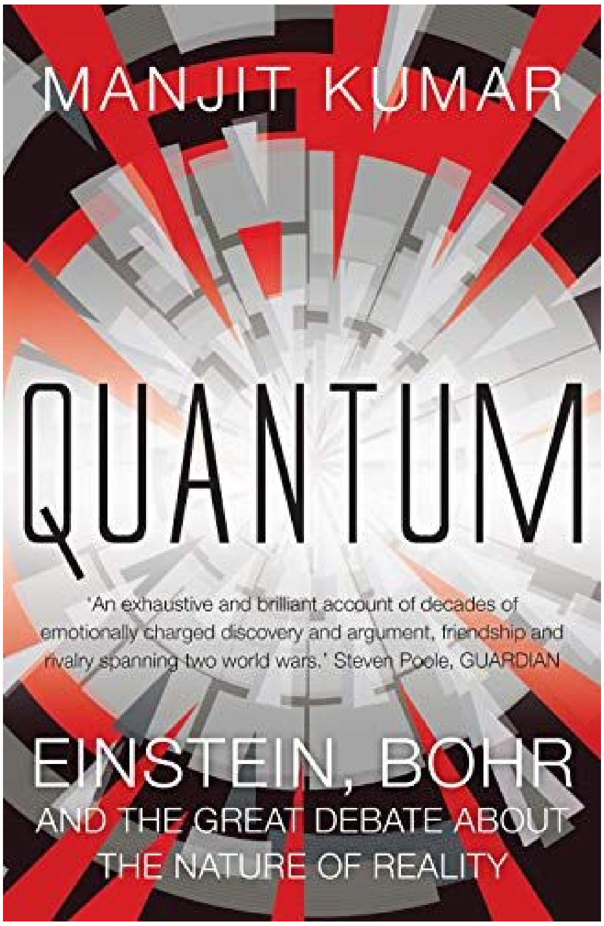
The closest that Polkinghorne gets to a "draw the rest of the quantum theory" moment is probably when he is explaining the EPR paradox, and says:

> "An alert reader may query all this talk about instantaneous change. Does not special relativity prohibit something at 1 having any effect at 2 until there has been time for the transmission of an influence moving with at most the velocity of light? Not quite. What relativity actually prohibits is the instantaneous transmission of information, of a kind that would permit the immediate synchronization of a clock at 2 with a clock at 1. It turns out that the EPR kind of entanglement does not permit the conveyance of messages of that kind. The reason is that its togetherness-in-separation takes the form of correlations between what is happening at 1 and what is happening at 2 and no message can be read out of these correlations without knowledge of what is happening at both ends. It is as if a singer at 1 was singing a random series of notes and a singer at 2 was also singing a random series of notes and only if one were able to hear them both together would one realize that the two singers were in some kind of harmony with each other. Realizing this is so warns us against embracing the kind of 'quantum hype' argument that incorrectly asserts that EPR 'proves' that telepathy is possible" [40].

This formulation is not intuitive at all. What counts as "information" in this case? the reader is left with lots of questions.

4.2 *Quantum* by Manjit Kumar

With a length of more than 400 pages, among all the books analyzed for this thesis, *Quantum* by Manjit Kumar is the one with the deepest historical research. Kumar is always very careful to immerse his physics in historical context, and he details the lives of scientists and the broader historical picture at each step of the book. The book was shortlisted for the BBC Samuel Johnson Prize for Non-Fiction in 2009, and is a staple



of physics history for the general public. It's the clearest example of history-as-structure rather than mere backdrop.

The book spends lots of words on historical context and anecdotes that don't have any direct influence on physics. Here's an example, from the part of the book where Planck is introduced:

> "In October 1874, aged sixteen, Planck enrolled at Munich University and opted to study physics because of a burgeoning desire to understand the workings of nature. In contrast to the near-militaristic regime of the Gymnasiums, German universities allowed their students almost total freedom. With hardly any academic supervision and no fixed requirements, it was a system that enabled students to move from one university to another, taking courses as they pleased. Sooner or later those wishing to pursue an academic career took the courses by the pre-eminent professors at the most prestigious universities. After three years at Munich, where he was told 'it is hardly worth entering physics anymore' because there was nothing important left

to discover, Planck moved to the leading university in the German-speaking world, Berlin. With the creation of a unified Germany in the wake of the Prussian-led victory over France in the war of 1870–71, Berlin became the capital of a mighty new European nation. Situated at the confluence of the Havel and the Spree rivers, French war reparations allowed its rapid redevelopment as it sought to make itself the equal of London and Paris. A population of 865,000 in 1871 swelled to nearly 2 million by 1900, making Berlin the third-largest city in Europe. Among the new arrivals were Jews fleeing persecution in Eastern Europe, especially the pogroms in Tsarist Russia. Inevitably the cost of housing and living soared, leaving many homeless and destitute. Manufacturers of cardboard boxes advertised 'good and cheap boxes for habitation' as shanty towns sprung up in parts of the city" [27].

Once again, the depth of research that this book has is impressive. There are so many anecdotes and historical details that aren't found in any other book. All the "characters" (aka, the physicists that contribute to the creation and development of quantum mechanics) are introduced with lengthy paragraphs, no matter how small of a role they have played. It's a very human way of telling quantum mechanics, and it naturally constructs a narrative throughline of the book.

Here is another example of how Kumar introduces his characters:

"Born on 30 August 1871 in a small, single-storey wooden house in Spring Grove on New Zealand's South Island, Rutherford was the fourth of twelve children. His mother was a schoolteacher and his father ended up working in a flax mill. Given the harshness of life in the scattered rural community, James and Martha Rutherford did what they could to ensure that their children had a chance to go as far as talent and luck would carry them. For Ernest it meant a series of scholarships that took him to the other side of the world and Cambridge University. When he arrived at the Cavendish to study under Thomson in October 1895, Rutherford was far from the exuberant and self-confident man he would become within a few years. The transformation began as he continued work started in New Zealand on the detection of 'wireless' waves, later called radio waves. In only a matter of months Rutherford developed a much-improved detector and toyed with the idea of making money from it. Just in time, he realised that exploiting research for financial gain in a scientific culture where patents were rare would harm the chances of a young man yet to make his reputation. As the Italian Guglielmo Marconi amassed a fortune that could have been his, Rutherford never regretted abandoning his detector to explore a discovery that had been front-page news around the world" [27].

The pacing of this book is more relaxed, when compared to other books analyzed for this thesis. This is clearly a deliberate creative choice, and the pacing is maintained consistent throughout the whole text: it's always slow and deliberate and focused on historical context. The tradeoff for this creative choice is that less words are spent for explaining mathematics or quantum mechanics. For example, the EPR paper is explained, and it takes more than 3 pages to get over it [27].

A reader who is not interested in a lot of historical details will find this text quite boring and too slow, but every strong creative choice is bound to disappoint some section of the audience. A reader that, on the other hand, enjoys this level of detail, will walk away with an impressive amount of historical analysis, albeit not much new understanding of contemporary physics. This is, in my opinion, a winning strategy: the reader never feels overwhelmed by the new information that they are given, and gently climbs "the hill" throughout the whole book. The hardest chapter from a conceptual point of view is probably chapter 11, which still didn't feel overwhelming [27]. To give a better example of how gently Kumar makes his reader climb "the hill", here is the paragraph where he introduces the idea of probabilistic interpretation.

> "The Newtonian universe is purely deterministic with no room for chance. In it, a particle has a definite momentum and position at any given time. The forces that act on the particle determine the way its momentum and position vary in time. The only way that physicists such as James Clerk Maxwell and Ludwig Boltzmann could account for the properties of a gas that consists of many such particles was to use probability and settle for a statistical description. The forced retreat into a statistical analysis was due to the difficulties in tracking the motion of such an enormous number of particles. Probability was a consequence of human ignorance in a deterministic universe where everything unfolded according to the laws of nature. If the present state of any system and the forces acting upon it are known, then what happens to it in the future is already determined. In classical physics, determinism is bound by an umbilical cord to causality – the notion that every effect has a cause. Like two billiard balls colliding, when an electron slams into an atom it can be scattered in almost any direction. However, that is where the similarity ends, argued Born as he made a startling claim. When it comes to atomic collisions, physics could not answer the question 'What is the state after collision?', but only 'How probable is a given effect of the collision?' 'Here the whole problem of determinism arises', admitted Born. It was impossible to determine exactly where the electron was after the collision. The best that physics could do, he said, was to calculate the probability that the electron would be scattered through a certain angle. This was Born's 'new physical content', and it all hinged on his interpretation of the wave function. The wave function itself has no physical reality; it exists in the mysterious,

> ghost-like realm of the possible. It deals with abstract possibilities, like all the angles by which an electron could be scattered following a collision with an atom. There is a real world of difference between the possible and the probable. Born argued that the square of the wave function, a real rather than a complex number, inhabits the world of the probable. Squaring the wave function, for example, does not give the actual position of an electron, only the probability, the odds that it will found here rather than there. For example, if the value of the wave function of an electron at X is double its value at Y, then the probability of it being found at X is four times greater than the probability of finding it at Y. The electron could be found at X, Y or somewhere else. [...] It took Born the time between his two papers to fully grasp that he had introduced a new kind of probability into physics. 'quantum probability', for want of a better term, was not the classical probability of ignorance that could in theory be eliminated. It was an inherent feature of atomic reality. For example, the fact that it was impossible to predict when an individual atom would decay in a radioactive sample, amid the certainty that one would do so, was not due to a lack of knowledge but was the result of the probabilistic nature of the quantum rules that dictate radioactive decay" [27].

Despite the strong focus on history, Kumar uses clear analogies and writes good explanations. Where other books only hint at the impossibility of quantum teleportation [40, 28], he offers a good level of detail:

> "Bell theorem cannot decide whether quantum mechanics is complete or not, but only between it and any local hidden variables theory. If quantum mechanics is correct – and Einstein believed it was, since it had passed every experimental test in his day – then Bell's theorem implied that any hidden variables theory that replicated its results had to be nonlocal. Bohr would have regarded, as others do, the results of Alain Aspect's experiments as support for the Copenhagen interpretation. Einstein would probably have accepted the validity of the results testing Bell's inequality without attempting to save local reality through one of the loopholes in these experiments that remained to be closed. However, there was another way out that Einstein might have accepted, even though some have said that it violates the spirit of relativity – the no signalling theorem. It was discovered that it is impossible to exploit non-locality and quantum entanglement to communicate useful information instantaneously from one place to another, since any measurement of one particle of an entangled pair produces a completely random result. After performing such a measurement, an experimenter learns nothing more than the probabilities of the outcome of a possible measurement on the other entangled particle conducted at a distant location by a

colleague. Reality may be non-local, allowing faster-than-light influences between entangled pairs of particles in separate locations, but it is benign, with no 'spooky communication at a distance'" [27].

4.3 *Six Easy Pieces* by Richard Feynman, Robert Leighton and Matthew Sands

Between 1961 and 1964, Richard Feynman delivered a series of lectures at the California Institute of Technology that subsequently achieved widespread popularity. These lectures were recorded, later published online, and subsequently compiled into the three-volume textbook series *The Feynman Lectures on Physics*. Two additional shorter works were later derived from them for a general audience: *Six Easy Pieces*, which addresses topics in classical physics and quantum mechanics, and *Six Not-So-Easy Pieces*, which covers special and general relativity. Given that this thesis is primarily concerned with the popularization of quantum mechanics, the focus here will be restricted to Chapter 6 of *Six Easy Pieces*.

The influence of these lectures on subsequent popular accounts of quantum mechanics is considerable. Numerous introductory texts reference Feynman's work, particularly in discussions of the double-slit experiment. Gribbin, for instance, draws extensively from Feynman in the section entitled "The experiment with two holes" [1]. Ananthaswamy characterizes the *Feynman Lectures* as "an hour of spellbinding oratory" [2], similarly relying on them for his explanation of the double-slit experiment. Baggott explicitly cites Volume III of the *Feynman Lectures* [47], while Cox and Forshaw acknowledge their debt to "Richard Feynman's more transparent approach to the quantum world" and list "Feynman Lectures on Physics" in their further reading section [28]. Hey and Walters also frequently quote the *Feynman Lectures on Physics* and include them in their recommended reading list [36]. The widespread circulation of these works is further reflected in anecdotal evidence: when compiling an initial corpus of widely read physics books for this thesis, professors and peers overwhelmingly recommended *Six Easy Pieces* for readers without formal training in physics but with an interest in quantum mechanics. Even works not directly quoting from the lectures reveal their influence; Philip Ball's *Beyond Weird*, for example, is framed as a response to Feynman's well-known 1965 remark that "I think I can safely say that nobody understands quantum mechanics" [39].

One notable feature of Feynman's approach is his sustained effort to communicate both qualitatively and quantitatively. He devotes substantial portions of his lectures to cultivating accurate mental models prior to introducing formal mathematical frameworks or calculations. As a result, the *Feynman Lectures* maintain a high level of accessibility for readers with little prior exposure to physics. Their successful adaptation into popular books may be attributed to the clarity and pedagogical design of the original lectures.

In the domains of atomic theory and classical mechanics, accessibility is enhanced through analogies drawn from everyday experience. However, in introducing quantum mechanics, Feynman emphasizes its radical departure from intuition: “Quantum mechanics is the description of the behavior of matter in all its details and, in particular, of the happenings on an atomic scale. Things on a very small scale behave like nothing that you have any direct experience about. They do not behave like waves, they do not behave like particles, they do not behave like clouds, or billiard balls, or weights on springs, or like anything that you have ever seen” [37]. He further underscores this point: “because atomic behavior is so unlike ordinary experience, it is very difficult to get used to and it appears peculiar and mysterious to everyone, both to the novice and to the experienced physicist. Even the experts do not understand it the way they would like to, and it is perfectly reasonable that they should not, because all of direct, human experience and human intuition applies to large objects” [37].

The clarity of the lecture format is exemplified in the following passage:

> "Let us write this in the form of a “Proposition”: Proposition A: Each electron either goes through hole 1 or it goes through hole 2.
>
> Assuming Proposition A, all electrons that arrive at the backstop can be divided into two classes: (1) those that come through hole 1, and (2) those that come through hole 2. So our observed curve must be the sum of the effects of the electrons which come through hole 1 and the electrons which come through hole 2. Let us check this idea by experiment. First, we will make a measurement for those electrons that come through hole 1. We block off hole 2 and make our counts of the clicks from the detector. From the clicking rate, we get . [...]. The result seems quite reasonable. In a similar way, we measure P_2, the probability distribution for the electrons that come through hole 2. The result of this measurement is also drawn in the figure. The result P_{12} obtained with both holes open is clearly not the sum of P_1 and P_2, the probabilities for each hole alone. In analogy with our water-wave experiment, we say: “There is interference.” For electrons $P_{12} \neq P_1 + P_2$ How can such an interference come about?" [37].

Here, Feynman underscores the insufficiency of classical intuitions, emphasizing instead the conceptual limits faced by learners: “Historically, the electron, for example, was thought to behave like a particle, and then it was found that in many respects it behaved like a wave. So it really behaves like neither. Now we have given up. We say: It is like neither” [37]. The phrasing “now we have given up” anticipates his later often-quoted statement that “I think no one understands quantum mechanics.” The enduring popularity of the *Feynman Lectures* has arguably reinforced the widespread impression that quantum mechanics is intrinsically unintelligible, though this impression may equally be attributed to the subject’s inherent difficulty and counterintuitive character.

Feynman makes this point explicitly in a passage that is among the most frequently cited from his lectures:

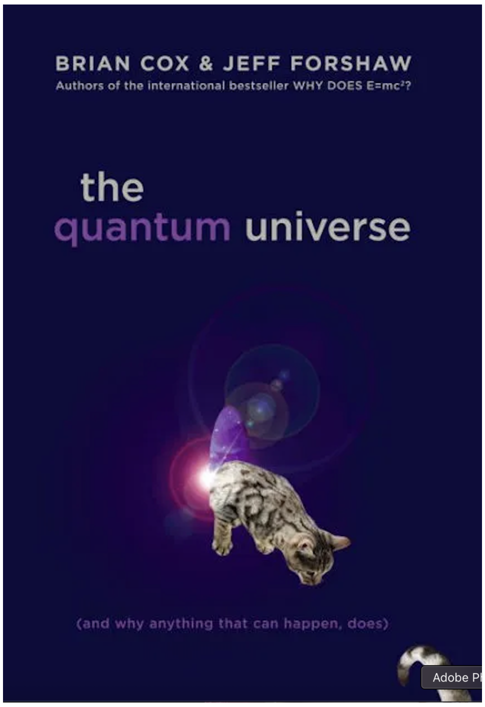
> "We choose to examine a phenomenon which is impossible, absolutely impossible, to explain in any classical way, and which has in it the heart of quantum mechanics. In reality, it contains the only mystery. We cannot explain the mystery in the sense of "explaining" how it works. We will tell you how it works. In telling you how it works we will have told you about the basic peculiarities of all quantum mechanics" [37]

This prefaces his presentation of the double-slit experiment. Remarks such as "It is all quite mysterious. And the more you look at it the more mysterious it seems" [37]. serve both to highlight the counterintuitive nature of quantum theory and to sustain reader engagement.

A final example of Feynman's effectiveness as a science communicator is the following passage:

> "Is there not some way we can see the electrons without disturbing them? We learned in an earlier chapter that the momentum carried by a "photon" is inversely proportional to its wavelength ($p = h/l$). Certainly the jolt given to the electron when the photon is scattered toward our eye depends on the momentum that photon carries. Aha! If we want to disturb the electrons only slightly we should not have lowered the intensity of the light; we should have lowered its frequency (the same as increasing its wavelength). Let us use light of a redder color. We could even use infrared light, or radiowaves (like radar), and "see" where the electron went with the help of some equipment that can "see" light of these longer wavelengths. If we use "gentler" light perhaps we can avoid disturbing the electrons so much. Let us try the experiment with longer waves. [...] At first, nothing seems to change. The results are the same. Then a terrible thing happens. You remember that when we discussed the microscope we pointed out that, due to the wave nature of the light, there is a limitation on how close two spots can be and still be seen as two separate spots. This distance is of the order of the wavelength of light. So now, when we make the wavelength longer than the distance between our holes, we see a big fuzzy flash when the light is scattered by the electrons. We can no longer tell which hole the electron went through! We just know it went somewhere" [2].

As Ananthaswamy observes [2], Feynman's caution that "we should say right away that you should not try to set up this experiment (as you could have done with the two we have already described). This experiment has never been done in just this way."



reads as particularly striking in retrospect, given that the 2022 Nobel Prize in Physics was awarded to researchers who successfully realized an experimental confirmation of the double-slit setup, thereby validating quantum mechanical predictions [56].

4.4 *The Quantum Universe* by Brian Cox and Jeff Forshaw

Cox and Forshaw take an interesting approach, that is quite unique in the landscape of popular quantum mechanics books. This book tests whether high-level abstraction can remain accessible via consistent visual metaphors, offering a counterpoint to history-led or anecdote-led approaches.

The first chapter *Something strange is afoot* starts in a way that is similar to other popular quantum mechanics books, talking about some of the historical context before the quantum revolution, explaining Newton's laws and Bohr's atomic model, and other interesting pre-quantum physics ideas, all without using any mathematics. Chapter 2 *Being in two places at once* introduces the double-slit experiment as "a central mystery" [28] of quantum mechanics, also without relying on mathematics.

But then, in chapter 3 *What is a particle?* the authors introduce a clever way to talk about wave mechanics, without having to rely on trigonometry formulas. They ask the reader to imagine a clock, and to connect the hand of this clock to peaks and troughs of

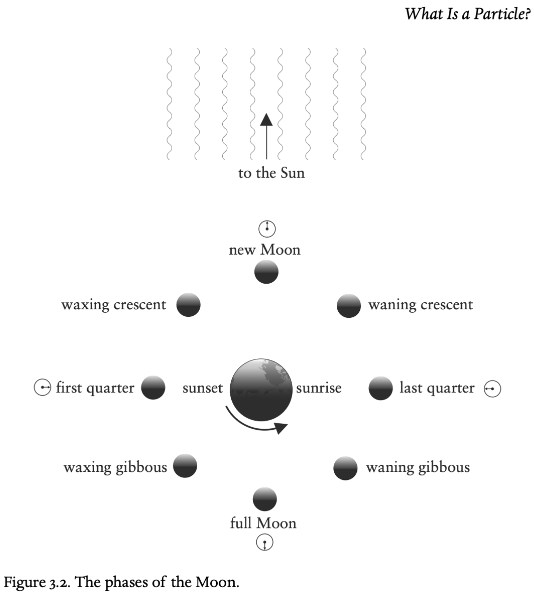


Figure 4.1: The phases of the Moon and the hand of a clock, which are about to be connected to wave mechanics, illustrated in *The quantum universe* by Cox and Forshaw

a wave.

Then, in the next figure, the link between phases of a clock and phases of a wave is made more explicit. They say "Have a look at Figure 3.2. One way to represent a phase is as a clock face with a single hand rotating around. This gives us the freedom to represent visually a full 360 degrees worth of possibilities: the clock hand can point to 12 o'clock, 3 o'clock, 9 o'clock and all points in between" [28]. Figure 4.1 is clearly helpful in illustrating the phenomenon.

The authors also take care, frequently and all throughout the book, to reassure the reader about the utility of this abstraction. In fact, they highlight abstraction as one of the core features of physics, writing:

> "the use of abstract pictures or symbols to represent real things is absolutely fundamental in physics – this is essentially what physicists use mathematics for. The power of the approach comes when the abstract pictures can be manipulated using simple rules to make firm predictions about the real world. As we'll see in a moment, the clock faces will allow us to do just this because they are able to keep track of the relative positions of the peaks and troughs of waves. This in turn will allow us to calculate whether they will cancel or reinforce one another when they meet" [28].

And then again, further along down the explanation:

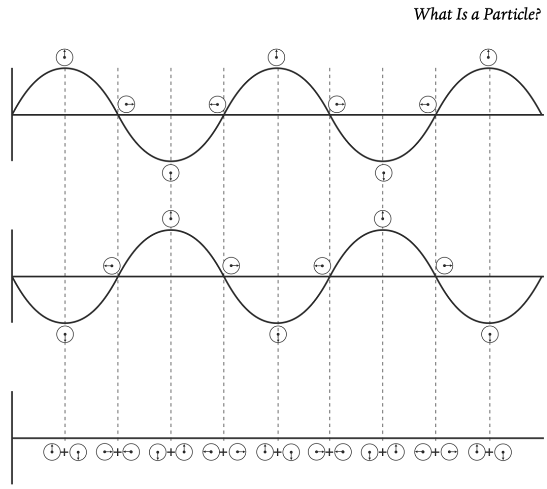


Figure 3.3. Two waves arranged such that they cancel out completely. The top wave is out of phase with the second wave, i.e. peaks align with troughs. When the two waves are added together they cancel out to produce nothing – as illustrated at the bottom where the 'wave' is flat-lining.

> "using clocks to describe waves does, at this stage, seem like we are over-complicating matters. Surely if we want to add together two water waves, then all we need to do is add the heights of each of the waves and we don't need clocks at all. This is certainly true for water waves, but we are not being perverse and we have introduced the clocks for a very good reason. We will discover soon enough that the extra flexibility they allow is absolutely necessary when we come to use them to describe quantum particles. With this in mind, we shall now spend a little time inventing a precise rule for adding clocks" [28].

The reader gets a clear message that this abstraction is leading to something. They are told that "At some points in this book and at this point especially, things are abstract. To keep ourselves from succumbing to dizzying confusion, we should remember the bigger picture" [28] at the end of a particularly abstract paragraph.

One possible downside of this approach could be that some people might be turned off by the high demands of cognitive effort that this book makes from its readers. Nonetheless, this book finds a good compromise between conveying the importance of mathematics and abstract thinking, and doing away with jargon when it's not strictly needed. The authors use the abstraction of clocks and phases throughout most of the book, and they ground abstract ideas like Heisenberg's Uncertainty Principle or the De Broglie hypothesis.

By the time chapter 6 *The music of atoms* rolls around, the authors need to introduce a few more concepts from classical physics to make sense of their explanations. They do a good job at grounding their explanations in day-to-day experience, but this is where the book starts to become steep, and the reader is perhaps asked to bite off a bit more than they're able to chew. The authors still try to remind their readers of the importance of this abstract legwork, saying "we are going to proceed by exploiting what we learned in the previous chapter about the wave-like properties of quantum particles, because, when it comes to describing atoms, the wave picture really simplifies things and we can make a good deal of progress without having to worry about shrinking, winding and adding clocks. Always bear in mind, though, that the waves are a convenient shorthand for what is going on 'under the bonnet'" [28]. Chapter 6 is the first moment in the book where "the hill" happens, and the authors start demanding a bit more of their readers.

The authors are able to capitalize on the work that they asked from their readers in the first half of the book, by using the clock abstraction to explain how atoms work, why the periodic table looks the way that it does, what is spin and how transistors work. The reader who puts in the work is rewarded with a sense of understanding that is not common for a popular book. Of course, not all readers are going to be up for the challenge.

Chapter 10 *Interaction* is more disconnected from the others: the information in this chapter does not follow from the previous ones, as easily as it was for other chapters. It is still a good explanation, but the reader could walk away with the feeling that a lot of new principles and arbitrary rules have been introduced, and not justified as thoroughly as the rest of the book. This chapter is the closest that this book comes to having a "draw the rest of the quantum theory" part, together with chapter 6.

Cox and Forshaw also use "mathematical boxes" to confine the more math heavy sections of their book. In the bonus chapter, they calculate the largest possible mass of a white dwarf, "using nothing more than a pen, paper and a little thought" [28]. Since the rest of the book is so heavy in abstraction, however, the reader is still left with an appreciation of the mathematics behind quantum mechanics, and the importance of abstraction and rigor is clear.

4.5 *Seven Brief Lessons on Physics* by Carlo Rovelli

Seven Brief Lessons on Physics was firstly published as *Sette Brevi Lezioni di Fisica* in 2014, and almost immediately met with worldwide success. It is one of the most sold popular physics books by an Italian author, which is why it was chosen for a more in depth analysis. I also happen to have read this book firstly when it came out, and it influenced me to pursue physics for my Bachelor's degree.

This books touches on many physics subjects, but since this thesis focuses on quantum mechanics, the focus will be kept on chapters 2 and 4.

Like many other science communicators, Rovelli starts the story of quantum mechanics from the ultraviolet catastrophe, and Einstein's brilliant solution. Even if the book he wrote is very short (the shortest one among those considered in this thesis) he takes the time to show the human side of physics. It's a good example of the usage of history of physics and personal anecdotes to make physics more accessible. Rovelli writes:

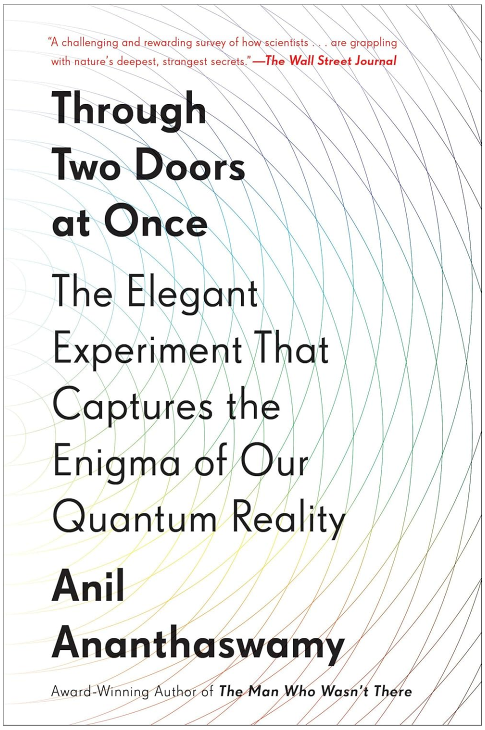
> "Einstein showed that light is made of packets: particles of light. Today we call these 'photons'. He wrote, in the introduction to his article: "It seems to me that the observations associated with blackbody radiation, fluorescence, the production of cathode rays by ultraviolet light, and other related phenomena connected with the emission or transformation of light are more readily understood if one assumes that the energy of light is discontinuously distributed in space. In accordance with the assumption to be considered here, the energy of a light ray spreading out from a point source is not continuously distributed over an increasing space but consists of a finite number of 'energy quanta' which are localized at points in space, which move without dividing, and which can only be produced and absorbed as complete units". These simple and clear lines are the real birth certificate of quantum theory. Note the wonderful initial 'It seems to me...', which recalls the 'I think...' with which Darwin introduces in his notebooks the great idea that species evolve, or the 'hesitation' spoken of by Faraday when introducing for the first time the revolutionary idea of magnetic fields. Genius hesitates" [42].

Finally, Rovelli has a particular ability to weave his personal experience as a theoretical physicist, as a philosopher, and as a human being into an awe inspiring prose. The reader gets a clear sense that they are listening to an expert, who has thought about these topics for a long time in a specialised field, and that has developed personal opinions and taste for them. Here's one of the clearest examples of this:

> "But, alas, no proton was ever seen disintegrating. The beautiful theory, $SU5$, despite its considerable elegance, was not to the good Lord's liking. The story is perhaps repeating itself now with a group of theories known as "supersymmetric", which predict the existence of a new class of particles. Throughout my career I have listened to colleagues awaiting with complete confidence the imminent appearance of these particles. Days, months, years and decades have passed – but the supersymmetric particles have not yet manifested themselves. Physics is not only a history of successes" [42].

4.6 *Through Two Doors at Once* by Anil Ananthaswamy

Anil Ananthaswamy has a gift for weaving history of physics, personal anecdotes about the lives of scientists, philosophy of science and quantum mechanics theory. His book



Through Two Doors at Once is entirely dedicated to the double slit experiment, and it features very heavily the history of experimental physics, more than most other popular quantum mechanics books.

The strength of this book (besides Ananthaswamy's captivating prose) are the interviews that the author conducted with the protagonists of quantum theory that are still alive, like Roger Penrose, Alain Aspect and many more.

Through these interviews (and through the extensive historical research that Ananthaswamy put in the book) the reader has a strong feeling that they are getting to know the physicists behind the theory, both the big names and the protagonists that are less known. As an example, the choice to talk about Bush's experiment with oil droplets, as a macroscopic analogy for bohmian mechanics, original and not seen in many other books. As another example, here is a paragraph where Goldstein expresses philosophical doubts about the interpretation of quantum mechanics:

> "Goldstein then expressed some remorse for those thoughts about Einstein. "I think that was very unfair, but anyway, that's what I thought then," he said. "You could say I wasn't smart enough to see what a bunch of crap that was, so I swallowed it. I thought if I learned the mathematics better and looked into it carefully, I would really understand it all one day. [But] the more I learned, the more clear it became that we were all hoodwinked." Strong words, but not unusual from those who have developed a distaste for the orthodoxy. As

> Goldstein probed further into the mathematics of standard quantum theory, he was unable to make sense of what it's about. What are the fundamental entities of reality? Is it a theory about particles? Is it about waves? Is it a theory of measurements and observations? Is it a theory of wavefunctions? Is the wavefunction ontic (meaning it is something) or is it epistemic (in that the wavefunction represents our knowledge about something); is the wavefunction objective or subjective? Goldstein wasn't done expressing his concerns about orthodox quantum mechanics. "Are there particles before you look? Do they have positions before you look? According to textbook quantum mechanics, presumably not. Then what do you have before you look? Or does looking create reality? Is that clear from the usual theory, textbook theory? No, it's not"" [2].

On their own, the questions in this paragraph, questions like "what are the fundamental entities of reality?" or "are there particles before you look?", would be a lot to digest for a reader in the span of a single page. But because there is that strong element of connection to the scientist, the reader feels comforted, as if they were in a deep conversation with an old friend that just so happens to be an expert in quantum mechanics.

I'll give another example, with the following paragraph from earlier in the book:

> "Maxwell argued that light too is an electromagnetic wave. But his ideas met with some resistance. While physicists could imagine electromagnetic waves moving through a medium, such as a wire, they had trouble envisaging light as an electromagnetic wave moving through the vacuum of space, as it would have to. But even before questions about the nature of light could be answered, Maxwell's hypothesis about electromagnetism had to be proved. In 1879, the Prussian Academy of Sciences (in Berlin) put out a call for what came to be called the Berlin Prize problem. The prize was for experimentally verifying Maxwell's ideas. Entries were due by March 1, 1882, with the winner to be awarded 100 ducats (a ducat was either a gold or a silver coin used in Europe during the Middle Ages, and even into the nineteenth and early twentieth centuries). One of the scientists thought most likely to win the prize was the prodigiously talented German physicist Heinrich Hertz. That year, Hertz considered the problem but gave up on it, for he could see no clear experimental way forward. "But in spite of having abandoned the solution at that time, I still felt ambitious to discover it by some other method" he later wrote" [2].

The new "step" up the hill that this paragraph introduces is the electromagnetic nature of light: the reader is introduced to the idea that light is a wave, an oscillation

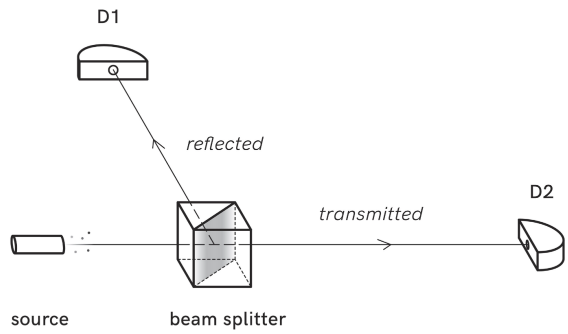


Figure 4.2: One of the many illustrations of the double slit experiment in Ananthaswamy's book [2]

of the electromagnetic field. But the idea is accompanied by a lot of historical context, like the proverbial medicine is accompanied by sugar to make it go down easier.

This book has some sections where the "hill" gets steeper, like all the others. It's a book about quantum mechanics after all, it's bound to demand some abstraction from its reader, who hopefully is up for it. Instead of asking the reader to do mathematical calculations, however, Ananthaswamy takes his readers along a journey through many variations of the double slit experiment. Each version is accompanied by illustrations to present its ideas more clearly. An example is in figure **??**.

Another example is in chapter 7, where the author is explaining Gravity-induced collapse of the wavefunction. Ananthaswamy relies heavily on an interview he conducted with Roger Penrose, writing:

> "On that rather nippy English afternoon, sitting at a wooden table on a deck in his backyard, Penrose took off his glasses and placed them on the table. Glasses have mass, and according to general relativity, they will warp or curve spacetime in their vicinity. Gravity is the curvature of spacetime: the more massive the object, the greater the curvature (black holes really put a dent in spacetime, a pair of glasses, not so much). But if the glasses were in a superposition of being in two places—Penrose moved them back and forth for his show-and-tell—then the glasses at one location would warp spacetime one way, and another way at the second location". "Now, therefore, you have a superposition [of] two slightly different spacetimes," he said. And that, said Penrose, is an unstable situation that destroys the superposition rapidly if the mass displacement is large" [2].

The choice to put the history of physics, especially of experimental physics, is a winning one and the reader is supported throughout the text, as they climb the "hill" slowly and gently.

Finally, I want to observe that the beauty of the prose is not optional, for the success of this book. Ananthaswamy embeds all his narration in a vivid and interpersonally rich world. He talks about the attitudes of the scientists he has met, as well as the surrounding environment in which the experiments have been conducted. By doing so, he paints a picture of physics that is deeply human, made by real people in real places.

Chapter 5

When quantum mechanics is misunderstood

5.1 "Nobody understands quantum mechanics"

It is undeniable that the subject of quantum mechanics is abstract, counterintuitive, not very accessible and mathematically dense. Physicists themselves struggle with grasping it after years of college, so it's not realistic to expect authors of popular physics books to give a comprehensive explanation to their reader over the course of just a few hundred pages, with barely any mathematics in them.

As a way to reassure the audience, sometimes popular quantum mechanics authors will point out that the physicists in the early 1900s were confused about the experimental results too, and they will draw a parallel between the confusion that the reader might be experiencing, and the well-documented doubts about quantum theory that Einstein, Schrödinger, Heisenberg and others wrote about. Cox and Forshaw are explicit in drawing this parallel, writing "If you are having trouble swallowing this anarchic proposal – that we have to fill the entire Universe with little clocks in order to describe the behaviour of a single subatomic particle from one moment to the next – then you are in good company. Lifting the veil on quantum theory and attempting to interpret its inner workings is baffling to everyone. Niels Bohr famously wrote that 'Those who are not shocked when they first come across quantum mechanics cannot possibly have understood it', and Richard Feynman introduced volume III of The Feynman Lectures on Physics with the words: I think I can safely say that nobody understands quantum mechanics" [28]. And surely, the difficulty of quantum mechanics is a central point of Feynman's lectures on it: as he says in *Six Easy Pieces* when he talks about the double slit experiment: "One might still like to ask: "How does it work? What is the machinery behind the law?" No one has found any machinery behind the law. No one can "explain" any more than we have just "explained." No one will give you any deeper representation of the situation. We have no ideas about a more basic mechanism from which these results can be deduced" [37].

Other authors draw this parallel in more subtle ways, for example, by the book with a quote from a famous physicist expressing frustration or confusion. The quote from Bohr, for example, is rephrased in several books [27, 28, 1].

This framing can create confusion about physics, because it draws a parallel between the doubts that a lay reader experiences (which is usually due to lack of understanding or lack of deep mathematical background), and the objections that Bohr or Einstein wrote (which are sophisticated arguments at the edge of philosophy).

The tendency of physics communication to paint quantum mechanics as "spooky and weird" has been observed before [57]. In fact, Philip Ball explicitly calls it out in his book *Beyond Weird*, starting the introduction with the famous Feynman quote "I think I can safely say that nobody understands quantum mechanics." and then writing "This is a book about what quantum math really means [...] I am not saying that this book is going to give you the answer. We don't have an answer. [...] We do, however, now have better questions than we did when Feynman admitted his ignorance, and that counts for a lot" [39]. It's important to resist the temptation to frame quantum mechanics as inherently nonsensical. It surely is a complicated theory, but it has an internal logic that one can ultimately grasp, even if it requires years of dedicated work. Equally, the idea that "no one understands quantum mechanics" is simply outdated: many physicists and engineers around the world understand quantum mechanics, and use it every day to make predictions and perfect our devices.

5.2 "Draw the rest of the quantum theory"

"Draw the rest of the f****ng owl" is a popular meme online, originated from a parody art tutorial. You can see the original meme in 5.1

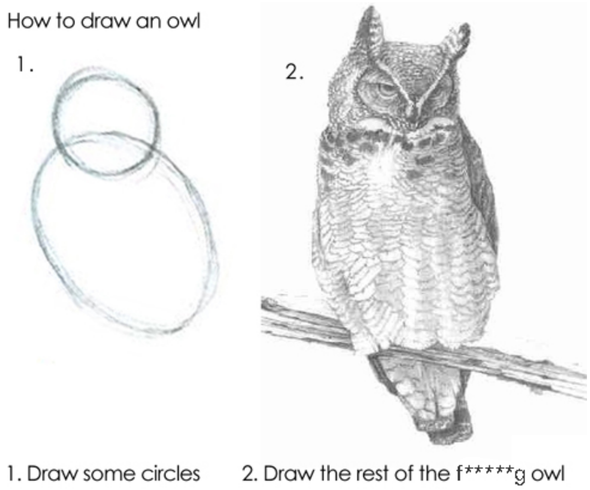


Figure 5.1: Original "Draw the rest of the owl" meme

On the internet, "draw the rest of the owl" is used as a comment to mock tutorials and explanations where steps are not adequately broken down, and the reader is left with the feeling that most of the process happens in one step. Some examples are in figure 5.2

If too much new information is dumped onto the reader too soon, then the "hill" becomes a wall, and the reader will feel a sense of overwhelm and frustration. This leads to a sense of "draw the rest of the owl" towards the entirety of quantum mechanics. While the "hill" is inevitable, there shouldn't be a "draw the rest of the quantum theory" passage in a popular book.

5.2.1 Example: *Quantum Physics for Babies*

Although children's books on quantum mechanics fall outside the primary scope of this thesis (for a thorough analysis of the genre, see Dihal, 2017 [13]), a brief consideration of Chris Ferrie's *Quantum Entanglement for Babies* can shed light on a broader narrative phenomenon frequently encountered in popular science writing: what I named the "draw the rest of the quantum theory" effect. By examining an overt and simplified example of this strategy, it becomes easier to identify its more subtle manifestations in complex and ostensibly adult-oriented texts.

Chris Ferrie is the author of a wholesome and widely popular series of science-themed board books marketed under the title *Baby University*. These books aim to introduce scientific concepts in the simplest possible terms, using clear visuals and minimal text to evoke curiosity rather than deliver detailed explanations.

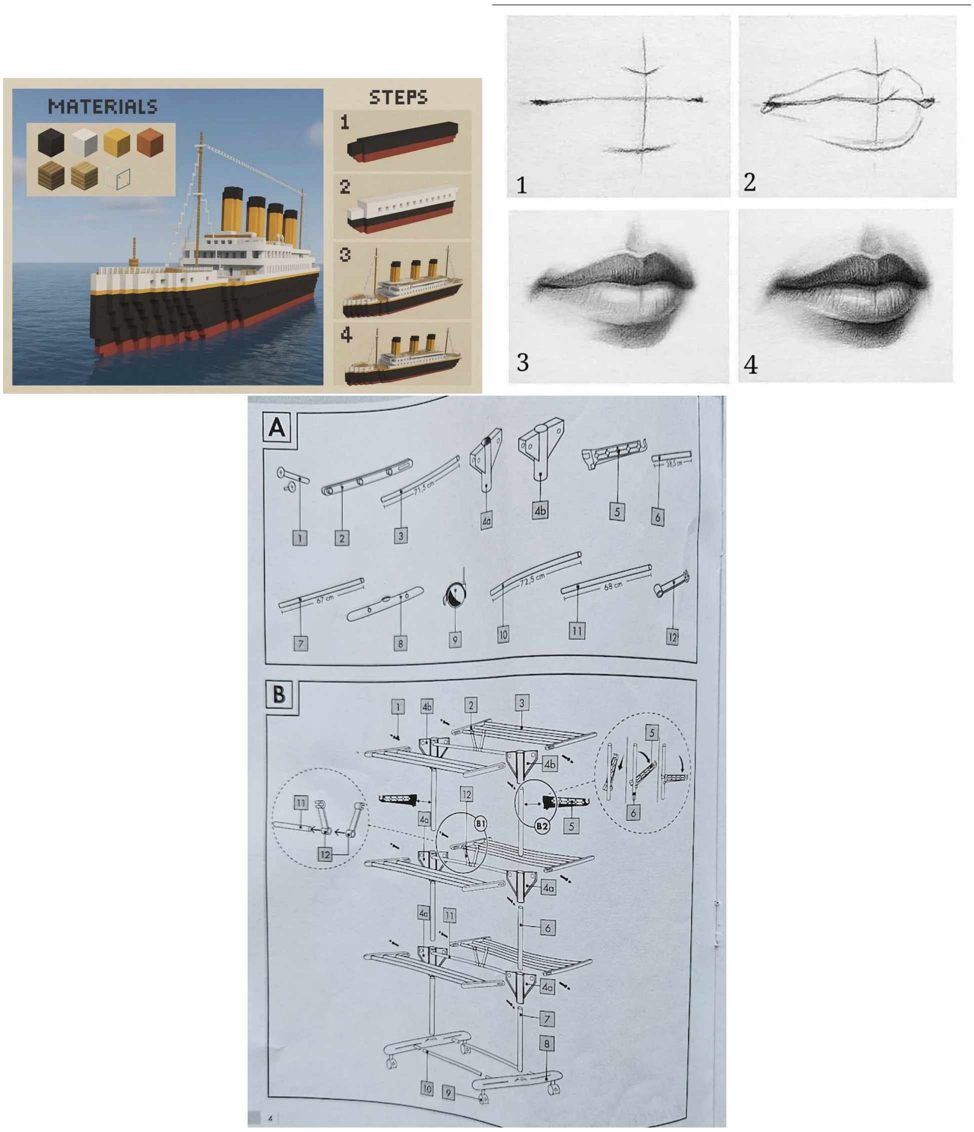


Figure 5.2: Some examples of tutorials that would warrant the comment "draw the rest of the owl".

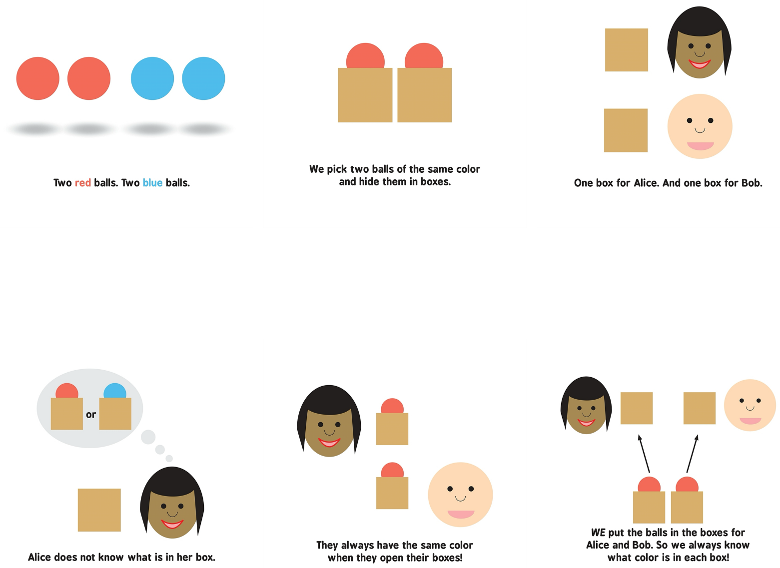


Figure 5.3: The first few pages of *Quantum Entanglement for Babies* [3].

The opening pages of *Quantum Entanglement for Babies* [3], shown in Figure 5.3, provide a straightforward and accessible start. The illustrations are simple, the text declarative, and the concepts limited to tangible ideas such as "particles" and "colors". However, as the narrative transitions into introducing actual principles of quantum mechanics, specifically, quantum measurement and entanglement, the coherence begins to waver. The text introduces statements such as "no one would know what color Alice or Bob will find" or "the particles decide what color they will be the moment they are measured," but it does so without offering any contextual grounding or theoretical scaffolding. These statements are likely unintelligible to readers unfamiliar with the quantum formalism, and their placement within a children's book emphasizes how fragile natural language becomes when pressed into service for describing quantum behavior.

Of course, the vagueness of this otherwise delightful board book is not a shortcoming of the author, but an inherent consequence of the form. It is not reasonable to expect a rigorous exposition of Bell's theorem in a publication aimed at toddlers. Indeed, in my experience, it is already quite difficult to persuade babies not to throw their food on the floor, so the probabilistic implications of quantum measurement will probably need to wait a few more years. The goal of a science-themed board book is not didactic precision but rather to entertain and spark early interest. In that regard, Ferrie's work

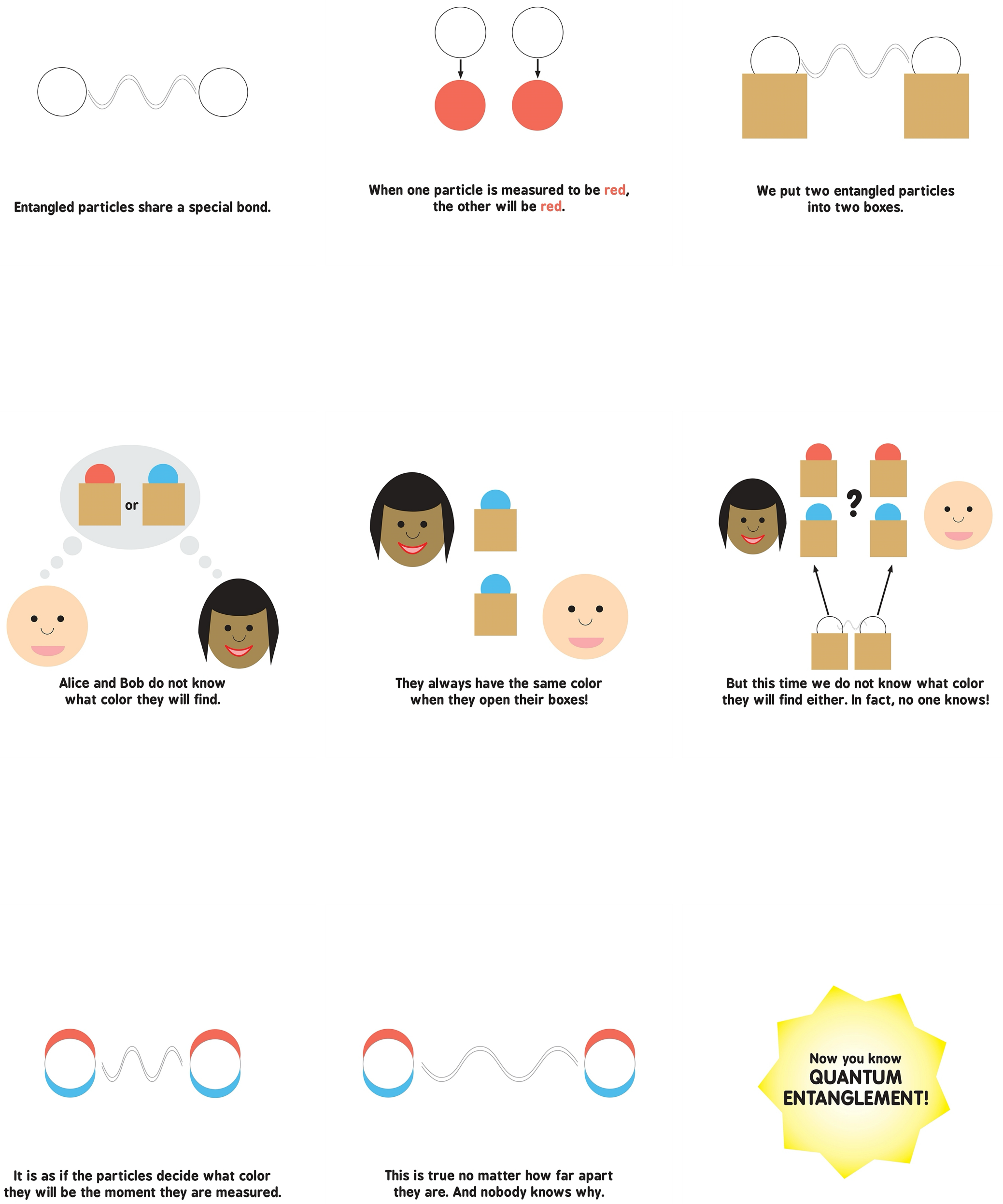


Figure 5.4: The last few pages of *Quantum Entanglement for Babies* [3]

is successful.

Nonetheless, this book offers a particularly transparent case of a much broader communicative challenge: the moment in which natural language falters in the face of quantum abstraction. In texts aimed at adult lay audiences, this breakdown tends to be more subtle. Writers often mask the limits of natural language with metaphor, narrative, or rhetorical reassurance. In Ferrie's board book, however, the limits are laid bare: the transition from easily grasped concepts to inscrutable statements is abrupt and jarring, highlighting the point at which the reader is implicitly asked to "draw the rest of the quantum theory" without adequate tools.

This makes *Quantum Entanglement for Babies* a useful diagnostic example. It illustrates, in highly condensed form, the communicative boundary where accessibility yields to abstraction. Understanding how this moment manifests, even in children's literature, can sharpen our awareness of similar patterns in more sophisticated popular science texts. Crucially, in successful popularizations, this boundary should not feel like a sudden wall but like a manageable incline: a gentle "hill" that the reader can climb with curiosity, rather than a mountain to stumble upon with confusion.

In the next section, some cases will be analyzed where the reader is not guided through the conceptual difficulties of quantum mechanics, but rather left alone in their confusion. Firstly, it's useful to bring up the example of two books published in the late 1970s, *The Tao of Physics* and *The Dancing Wu Li Masters*, whose great commercial success changed the landscape of popular quantum mechanics: these books have contributed largely to the popularisation of quantum mechanics and have indubitably sparked the interest of many future scientists and science writers, but they have also blurred the lines between the domains of science (quantum mechanics) and pseudoscience (New Age beliefs about consciousness and reality) and have many paragraphs that read like a "draw the rest of the quantum theory" moment, so to speak. And finally, some attention will be devoted to books where quantum mechanics is evoked not as a subject to be explained, but as a pseudo-explanation for sketchy concepts that lie completely outside of the scope of science.

5.3 The Fundamental Fysiks Group and the 1970s boom in popular science

The development of popular science is "nothing like a linear process of development" [58], but scholars agree that from the 1970s onward, popular science books saw a boom in sales and popularity, and popular physics books were part of this phenomenon [19].

The 1920s and 1930s had seen a wave of popular science books, particularly on relativity and cosmology. However, this trend was abruptly interrupted by the Second World War: the following decades (1940s, 1950s, and 1960s) were comparatively quiet in terms of popular physics publications, with the majority of books focusing on atomic physics and nuclear weapons [19]. After the three decades slump that followed World War II [59], "the New Age counter-culture of the late 1960s and 1970s [...] played a prominent role in the early stages of the late twentieth-century boom in popular physics, particularly in bringing quantum mechanics to a wide readership" [19]. It is therefore important to look closely at the role that the New Age movement had on the popularization of quantum mechanics.

The Fundamental Fysiks Group was founded in May 1975 at the University of Berkeley, as an informal discussion group for people who were interested in the philosophical implications of quantum theory [60]. Founding members included John Clauser (who went on to win a Nobel Prize, together with Alain Aspect, in 2022 [56]), Nick Herbert, Jack Sarfatti, Saul-Paul Sirag, Henry Stapp, and Fred Alan Wolf. Fritjof Capra would also join the group a few years later. Although the group's discussions were initially centered on quantum mechanics, the influence of the surrounding New Age culture was soon apparent: conversations often expanded to include topics such as telepathy, voodoo, spoon-bending, extrasensory perception, parapsychology, and other ideas inspired by 1960s and 1970s countercultural spirituality. By the mid-1970s, the cultural atmosphere was increasingly receptive to new ways of interpreting science. The New Age movement had reached peak popularity, and public interest in unconventional scientific explanations was growing. Books authored by members of the Fundamental Fysiks Group capitalized on this environment. In 1974, Fred Alan Wolf and Bob Toben published *Space-Time and Beyond: Toward an Explanation of the Unexplainable* to modest commercial success. The following year, Fritjof Capra's *The Tao of Physics* appeared, quickly becoming the most commercially successful and enduring product of the New Age physics movement. The unexpected success of *The Tao of Physics* encouraged publishers to seek out further works exploring the links between quantum mechanics, consciousness, and spirituality. This commercial interest led to the publication of *The Dancing Wu Li Masters* by Gary Zukav in 1979, supported by a substantially larger marketing budget, compared to Capra [60]. The success of these works also inspired numerous imitators, many of which misused the term "quantum" as a marketing buzzword. As Elizabeth Leane humorously notes, titles such as George Gilder's *Microcosm: The Quantum Revolution in Economics and Technology* (1989), Bobbi DePorter's *Quantum Learning* (1993), Branton Kenton's *Quantum Carrot: a new concept in small space organic gardening* (1987), and, my personal favorite, Kjell Enhager's *Quantum Golf: The Path to Golf Mastery* (1991) illustrate the wide and often absurd appropriation of quantum terminology [19].

The impact that Capra's and Zukav's book have had on the popularization of quantum mechanics is very noticeable. Leane tries to quantify it using the Arts and Humanities citation Index: in late 2005 when she conducted her research, she found that while Pagels's *The Cosmic Code* was cited in 18 articles and Gribbin's *In Search of Schrödinger's Cat* was cited in 35, and a surprising 93 articles cited Zukav's *The Dancing Wu Li Masters* and 158 cited Capra's *The Tao of Physics* [19].

One may reasonably ask why Capra's and Zukav's books were the ones that popularized quantum mechanics, especially given that physicists had previously attempted to write for general audiences. Perhaps the most significant prior example is Werner Heisenberg's *Physics and Philosophy* (1958), which also tries to directly engaged with the philosophical dimensions of quantum mechanics [34]. Capra himself draws extensively from the philosophical writings of both Heisenberg and Einstein in *The Tao of Physics* [61]. Nevertheless, these earlier works did not achieve the commercial success of Capra's and Zukav's books. Capra's success can be attributed to several factors. In addition to his competence as a physicist, he possessed a writing style that was simple and highly accessible. Unlike authors such as Heisenberg or Einstein, who presupposed a significant background in physics and philosophy, Capra's book "is intended for the general reader with an interest in Eastern mysticism who need not necessarily know anything about physics" [61]. Similarly, *The Dancing Wu Li Masters* "is written for intelligent people who want to know about advanced physics but who are ignorant of its terminology and, perhaps, of its mathematics" [51]. Zukav conceptualizes himself and his book as a "translation" from the world of theoretical physics to the everyday language, and he emphasizes his status as a non-physicist, playing on his biggest shared identity with the hypothetical reader. He writes "for better or for worse, my first qualification as a physicist is that, like you, I am not a physicist" [51]. As Asprem (2016) intelligently noticed:

> "The popularization process narrows the range of scientific representations that reach the public domain in structured ways: it attracts minimally counterintuitive representations, minimizes the massively counterintuitive, and re-represents (or translates) hard-to-process concepts in inferentially rich metaphors" [55].

Zukav and Capra wrote books that optimize better for these requests.

As discussed in the chapter "The role of mathematics in popular quantum mechanics books", most popular quantum mechanics books try to limit the use of mathematics and formulas in their prose: some skip it entirely, some relegate it to "mathematical boxes": parts of the book that are not necessary to understand the rest of the text. Zukav makes the same creative choice. While he admits that "no complete appreciation of physics is possible without mathematics", he explains that "there is no mathematics in The Dancing Wu Li Masters" because "most physicists are not able to explain physics very well without [mathematics]. This makes them very concise but, unfortunately, unintelligible. The fact is that most of us use words to do our explaining" [51]. Capra also "tried to present the main concepts and theories of modern physics without any mathematics and in non-technical language" [61]. Despite the lack of formulas, these books still have a lot of jargon. For example, the paragraph about hadrons in *The Tao of Physics* reads as: "The nucleons are not the only particles interacting through the strong interactions. In fact, the overwhelming majority are strongly interacting particles. Of all the particles known today, only five (and their antiparticles) do not participate in the strong interactions. These are the photon and the four 'leptons' listed in the top part of the table. Thus all the particles fall into two broad groups: leptons and 'hadrons', or strongly interacting particles. The hadrons are further divided into 'mesons' and 'baryons' which differ in various ways, one of them being that all baryons have distinct antiparticles, whereas a meson can be its own antiparticle" [61]. This choice creates a sense of awe and curiosity in the reader, who is not familiar with quantum mechanics. Words like "quark" or "hadrons" or "spin measurement" are explained, but the impossibility to anchor these words in mathematics (or in day-to-day experience) creates an aura of mystery, parallel to the feeling that words like "chi" or "dao" create in western audiences who are not familiar with eastern religions.

The challenge of creating a popular book about both quantum mechanics and eastern mysticism, aimed at an audience of western laypeople, is surely remarkable, and the commercial success of both Capra's and Zukav's books could be seen as a success. These books surely introduced the topic of quantum mechanics (and modern theoretical physics in general) to a crowd that would have been indifferent to them. Ananthaswamy credits Zukav in the acknowledgements of his book, writing "I remember being thrilled by Gary Zukav's Dancing Wu Li Masters when I read it in the 1980s. The mysteries of quantum physics came alive" [2]. It is also worth noticing that one of the most widely sold books among the ones analysed for this thesis, Rovelli's *Seven Brief Lessons on Physics*, also relies heavily on awe inspiring metaphors, connects theoretical physics with art and philosophy, and tries to be very short and concise.

However, the picture of physics that laypeople will get from these works could be skewed: quantum mechanics is narrated as revolutionary and disruptive, and praised for its ability to move away from the old deterministic paradigm of science. Capra argues that both quantum mechanics and Eastern mysticism challenge Western materialist traditions [61]. Zukav writes "We are approaching the end of science. "The end of science" does not mean the end of the "unresting endeavor and continually progressing development" of more and more comprehensive and useful physical theories. [...] The "end of science" means the coming of western civilization, in its own time and in its own way, into the higher dimensions of human experience" [51]. While it is true that quantum mechanics has posed interesting challenges to the field of physics, it is very unlikely that "the end of science" is in the near future. Instead of a newfound appreciation for science, the reader is likely to come out of these books with the impression that the scientific method has been rendered obsolete and is on the verge of being abandoned, which is not rooted in reality.

The popularization of quantum mechanics owes much, albeit reluctantly, to its association with New Age movements. Pagels's *The Cosmic Code* and Talbot's *Beyond the Quantum* (which has been left out of this thesis) are published by Bantam New Age books, suggesting that the market for quantum explanations of new age ideas hasn't died down [25, 62]. This is despite Pagels's explicit dismissal of claims that Bell's work "verified telepathy or the mystical notion that all parts of the universe are instantaneously interconnected" as "rubbish" [25].

Many of the books analyzed in this thesis were published in the 1980s and later, in response to the widespread appropriation of the term "quantum" by New Age discourse. Consequently, a lot of authors take great care to distance their work from pseudoscientific interpretations, often including dismissive remarks about topics such as ESP, voodoo, and alternative medicine. Polkinghorne explicitly warns his readers that "the EPR effect does not offer an explanation of telepathy, for its degree of mutual entanglement is not one that could facilitate the transfer of information" [40]. Similarly, Rae warns that "there is nothing analogous to the photon pair in the ESP case" [49]. David Deutsch pointedly remarks that "shoddy explanations chat yield correct predictions are two a penny, as UFO enthusiasts, conspiracy-theorists and pseudo-scientists of every variety should (but never do) bear in mind" [50]. Gribbin suggests that combatting pseudoscientific appropriations of quantum mechanics is one of his main motivations for writing his book, writing: "In the late 1970s and early 1980s, books and articles began to appear attempting, with varying success, to introduce the strange world of the quantum to a nonscientific audience. Some of these alleged "popularizations" were so outrageously far from the truth that I could not imagine any reader discovering the truth and beauty of science by reading them, and I began to feel moved to do the job properly" [1]. In a landscape still saturated with pseudoscientific claims, these authors recognize the importance of drawing firm boundaries between legitimate physics and speculative pseudoscience.

Still, the field of popular quantum mechanics books might not have seen such a big commercial success, if it wasn't for the 1970s New Age popularizations, and the influence of the New Age counterculture is still all over the field. Popular quantum mechanics books written during the 1970s, most of which were heavily influenced by New Age, have had a fundamental role in the commercial success and popularization of the subject of quantum mechanics, at large. In many ways, the contemporary popularization of quantum mechanics can be described as post-New Age.

5.3.1 Misunderstanding quantum on purpose

Among the popular texts that reference quantum mechanics and that have been influenced heavily by New Age thought, there exists a significant spectrum in terms of both scientific accuracy and communicative intent. On one end of this spectrum are books like those by Capra and Zukav, which, while often vague or speculative, emerge from a genuine admiration for science and an earnest attempt to grapple with quantum theory. These works tend to blur the boundaries between scientific and philosophical discourse but retain an underlying respect for the subject matter and an aspiration toward intellectual sincerity.

By contrast, the works of Rhonda Byrne and Deepak Chopra represent a different category altogether: texts in which quantum mechanics is not merely misunderstood, but deliberately co-opted and misrepresented in order to lend a veneer of scientific legitimacy to wholly unscientific claims.

The ideas presented in these books are situated far from the mainstream of quantum mechanics. Certain fringe interpretations of quantum mechanics, however, can be reformulated into highly misleading versions of themselves. In particular, the role that human consciousness might play a fundamental role in the creation of the universe at large, was especially popular among the members of the Fundamental Fysiks Group, and has found an enthusiastic supporter in physicist and author Fred Alan Wolf. This idea represents one of the most misunderstood and exploited aspects of quantum theory, and for this reason, it is useful to briefly examine it.

In the 1960s, Eugene Wigner introduced the idea that human consciousness constitutes the primary mechanism through which quantum measurement occurs. This proposal was loosely inspired by von Neumann's formalism, which itself dates back to the origins of quantum theory in the 1930s. The theory came to be known as the "consciousness causes collapse" interpretation. However, "by 1970, Wigner changed his mind, doubting his own claims of consciousness playing a role in causing collapse" [2]. The consciousness causes collapse interpretation is referenced in more than one of the works analyzed in this thesis, but it is rarely discussed in detail, and it is never supported as the preferred interpretation. Rae summarizes the position by stating that "subjective theories postulate that superpositions collapse only when the information enters a human, conscious mind" [26]. Orzel characterizes it as a "most extreme variant of the Copenhagen interpretation" in which "the collapse requires not only a macroscopic measurement apparatus, but also a conscious observer to note the measurement" [38]. Ananthaswamy briefly entertains the idea, writing that "Wigner, after a careful analysis of von Neumann's formalism, concluded that the laws of quantum mechanics did not draw a line between the quantum and the classical. [...] The only thing, he reasoned, that could be responsible for the collapse of the wavefunction was consciousness. The act of perception by a conscious observer, Wigner argued, is the nail in the coffin for the wavefunction", but ultimately does not endorse it, noting that "very few physicists today put stock in Wigner's ideas" [2]. Polkinghorne provides a succinct critique of the interpretation, pointing to the well-known paradox of Schrödinger's cat: "surely the animal knows whether or not it is alive, without requiring human intervention to help it to that conclusion? Perhaps we should conclude, therefore, that cat consciousness is as effective at determinating quantum outcomes as is human consciousness. Where then do we stop? Can worms also collapse the wavefunction? They may not exactly be conscious, but one would tend to suppose that in some way or another they have the definite property of being either alive or dead. These kinds of difficulties have prevented most physicists from believing that hypothesizing a unique role for consciousness is the way to solve the measurement problem" [40]. Comparable philosophical issues are also identified by Gribbin, and by Hey and Walters [1, 36]. Ball likewise raises objections, writing that "perhaps most problematically of all, if wavefunction collapse depends on the intervention of a conscious being, what happened before intelligent life evolved on our planet?" [39].

When the role of consciousness in quantum mechanics is addressed by authors aiming to provide accurate accounts, the consciousness causes collapse interpretation is generally introduced only briefly, accompanied by a discussion of its major philosophical difficulties, and ultimately dismissed. This approach differs markedly from that of authors who invoke quantum mechanics in order to advance pseudoscientific claims. Two notable examples of such misleading usage of quantum mechanics and of quantum consciousness theory are *The Secret* by Byrne, and *Quantum Healing* and *Quantum Body* by Chopra.

Although Byrne does not directly cite Zukav or Capra, the influence of the Fundamental Fysiks Group remains evident in her work. She cites Fred Alan Wolf on multiple occasions, such as when he writes "quantum physics really begins to point to this discovery. It says that you can't have a Universe without mind entering into it, and that the mind is actually shaping the very thing that is being perceived" [63]. Her interpretations of modern physics are frequently inaccurate and presented with unwarranted confidence, in statements such as "Quantum physicists tell us that the entire Universe emerged from thought! You create your life through your thoughts and the law of attraction, and every single person does the same" or "Time is just an illusion. Einstein told us that. If this is the first time you have heard it, you may find it a hard concept to get your head around, because you see everything happening, one thing after the other. What quantum physicists and Einstein tell us is that everything is happening simultaneously". Byrne's engagement with modern physical theories is superficial and selective, invoked only insofar as it can be made to appear to support her own claims. She comes surprisingly close to acknowledging her bias, writing that "one of the most exciting things about living in this time is that the discoveries of quantum physics and new science are in total harmony with the teachings of The Secret, and with what all the great teachers have known throughout history". In other words, if quantum theory could not be mobilized in support of Byrne's arguments, it would likely be absent from her work altogether. This selective treatment is consistent with her stated disregard for the intellectual effort required to engage seriously with complex scientific subjects. She openly remarks, for example, "I never studied science or physics at school, and yet when I read complex books on quantum physics I understood them perfectly because I wanted to understand them. The study of quantum physics helped me to have a deeper understanding of The Secret, on an energetic level" [63].

Chopra is a widely known figure in the realm of alternative medicine and New Age spiritualism. He is the author of numerous best-selling books advocating for holistic health approaches grounded in Ayurveda, and he frequently invokes scientific-sounding language, particularly from quantum mechanics, to support metaphysical propositions that are unsupported by empirical evidence. Some of Chopra's most striking assertions include the idea that human beings can attain a state of "perfect health" that is entirely “free from disease” [64], one which "doesn’t experience pain" and even “doesn’t age or die” [65]. His book *Quantum Healing*, first published in 1989, is a paradigmatic example of the misuse of scientific language. The text is replete with buzzwords and pseudo-technical phrasing. For example, he describes thoughts as "impulses of intelligence in a field of consciousness", a formulation that mimics the structure of scientific discourse without adhering to its standards of clarity, falsifiability, or conceptual coherence.

Chopra and Byrne both routinely misappropriate terminology from quantum mechanics to lend credibility to mystical or metaphysical ideas. One particularly illustrative example is in Chopra’s work, with the description of a case of spontaneous cancer remission experienced by a woman named Chitra. Rather than acknowledging the medical uncertainty or complexity of such cases, Chopra frames the event as a "quantum leap in consciousness" that enabled the woman to “stay at a higher level of awareness” and “motivate the absence of cancer” [65]. He further suggests that in similar cases of unexplained recovery, “the faculty of inner awareness seems to have promoted a drastic jump, a quantum leap, in the healing mechanism” [65]. These statements exemplify a rhetorical strategy that relies on the mystique and perceived authority of quantum theory while dispensing with its actual meaning.

This rhetorical approach stands in sharp contrast to the strategies employed by legitimate popular science authors. In the works of other quantum mechanics communicators, for instance, the disorientation a reader may experience when first encountering quantum phenomena is acknowledged in a playful and reassuring tone. Rather than exploiting that confusion, writers like Polkinghorne or Gribbin carefully guide the reader back toward empirical science and conceptual clarity. Capra and Zukav, though not scientifically precise, similarly leverage the confusion to draw an allegorical parallel between the mysteries of quantum mechanics and the insights of Eastern mysticism. In these cases, the goal is to evoke wonder or philosophical reflection, albeit sometimes at the cost of precision.

Chopra’s and Byrne’s deployment of confusion operates quite differently. In their texts, the reader’s potential incomprehension of quantum theory is not resolved or redirected, but amplified and exploited. Scientific complexity becomes a rhetorical tool for obscuring rather than illuminating truth. In this model, confusion becomes an epistemic trap: if a reader finishes the book convinced that quantum mechanics is fundamentally beyond their understanding, that sense of alienation serves to make them more receptive to the author’s untestable metaphysical claims. The misuse of quantum terminology, in this context, is not an incidental inaccuracy: it is a calculated strategy designed to bolster the credibility of pseudoscientific positions under the guise of advanced theoretical science.

While Capra and Zukav might be said to invite readers to “draw the rest of the quantum theory” as an exercise in poetic or spiritual exploration, Chopra’s work does something more troubling: it leverages the counterintuitive ideas of quantum physics to blur the boundary between scientific discourse and mysticism, not to inspire, but to persuade the reader of claims that lack scientific foundation. The implications of this rhetorical move are serious, especially when applied to domains like health and medicine, where evidence-based practice is essential. As such, Chopra's and Byrne's work serves as a cautionary example of how quantum mechanics can be appropriated not merely for metaphor, but for the propagation of misinformation.

Conclusion

This thesis set out to examine what makes a popular book about quantum mechanics compelling, accessible, and intellectually meaningful. In doing so, it engaged with questions of language, metaphor, disciplinary authority, and reader expectation, drawing on a wide sample of texts and perspectives across science communication literature. Yet underlying this analytical project was also a more personal motivation: a long-standing fascination with quantum physics, and a desire, rooted in both academic training and professional experience in science communication, to understand how abstract and counterintuitive concepts can be effectively conveyed to non-expert audiences.

Popular science books about quantum mechanics occupy a paradoxical position in the cultural landscape. On the one hand, quantum theory is often considered among the most complex and conceptually demanding areas of modern physics. On the other, it has inspired a vast corpus of literature aimed at the general public. This tension, between inaccessibility and popular appeal, makes the genre uniquely rich for analysis. The books considered in this study were not merely vehicles for information transfer, but carefully crafted attempts to balance accuracy with engagement, abstraction with narrative, and mystery with clarity.

Throughout this thesis, I have explored how quantum concepts are framed through metaphor and analogy, how jargon and technical vocabulary are selectively introduced, and how the presence (or strategic absence) of mathematics affects accessibility. I have also reflected on how physics, and particularly quantum mechanics, is culturally positioned as both authoritative and enigmatic. These patterns are not merely stylistic; they reflect deeper assumptions about the nature of science, expertise, and communication. They also shape how readers relate to scientific knowledge, whether they are invited into it, distanced from it, or challenged by it.

My own background as a science communicator has inevitably shaped the questions posed in this work. Having experienced firsthand the complexities of translating science into narrative form, I approached this research not only as a reader and scholar, but also as a practitioner. This perspective has reinforced the importance of respecting readers' intelligence while avoiding unnecessary opacity; of using storytelling not as a distraction, but as a legitimate epistemological strategy; and of acknowledging that simplification, when done thoughtfully, can enhance rather than diminish intellectual engagement.

One of the broader implications of this study is that there is no singular formula for effective quantum science writing. Rather, different texts succeed in different ways: some by evoking wonder, others by focusing on philosophical implications, others still by grounding the abstract in tangible examples. But what unites the most compelling works is a kind of epistemic humility, a recognition that quantum mechanics resists final explanation, and that science communication is not about providing definitive answers, but about cultivating curiosity, dialogue, and thoughtful uncertainty.

This thesis is, in part, a foundation for my future work. I hope that its findings might serve as a starting point not only for my own science writing, but also for others interested in communicating complex scientific ideas in ways that are rigorous, honest, and emotionally resonant. In asking what makes a good quantum popular book, I have also asked what kind of relationship we want to foster between science and the public: one grounded in authority and distance, or one that invites participation, questioning, and engagement.

If there is one conclusion to draw from this exploration, it is that the power of science communication lies not only in the transmission of facts, but in the creation of space for readers to think, to imagine, and to encounter the strangeness of the quantum world on their own terms.

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