CHAPTER 1.5

The Bohr atom bound in cloth: Textual exposition of quantum theory in popular science books, 1918-1924

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Abstract

Analyzing a dozen popular books published in Europe between 1918 and 1924, this paper traces metaphors used to explain quantum theory of the atom to non-specialist audiences. The metaphor most commonly used is the planetary model, i.e., the comparison between the solar system and the atom. This idea predates quantum theory, but was given new attention in the light of Niels Bohr's 1913 model of the quantum atom. The planetary model suggested that the structures of the universe and of the atom, respectively, are more or less identical; it also provided physicists and others with a simple mental image for comprehending the invisible; and, finally, it offered epistemological assurance in a time of rapid scientific change. However, other metaphors stemming from classical physics and ordinary experience were used. It can be concluded that the exposition of quantum theory in popular science books was rich in metaphors for the Bohr Atom, allowing authors and audiences to reflect on the broader meaning of the new scientific results and theories.

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To the eye or to the touch, ordinary matter appears to be continuous; our dinner-table or the chairs on which we sit, seem to present an unbroken surface. We think that if there were too many holes the chairs would not be safe to sit on. Science, however, compels us to accept a quite different conception of what we are pleased to call "solid matter"; it is, in fact, something much more like the Irishman's definition of a net, "a number of holes tied together with pieces of string." Only it would be necessary to image the strings cut away until only the knots were left.[1]

1. Popular atomic physics in the early 20th century

Around 1920, publishers in several European countries were issuing books conveying the new quantum theory of the atom to non-specialist audiences. With the general acceptance of quantum theory amongst physicists after the First World War, science writers and physicists actively tried to present in everyday language the quantum-based conception of the constitution of matter. Although their efforts to make accessible to general audiences the new ideas about atomic structure spanned a large continuum in terms of accessibility and exposition, the authors all shared the notion that the quantum theory of the atom deserved to be popularized. The early 20th century proliferation of popular science books about quantum theory, but also about other big topics such as relativity, cosmology, and evolution, has led historians and rhetoricians of science to conclude that this period was characterized by a virtual popular science boom, but also by an increasing conceptual gap between science and the public.[2]

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1. Russell (1923), p. 7.
2. Leane (2007), p. 24 uses the term "boom in popular physics books;" Bowler

At least one of the popular "atomic books" entering the market for popular science in the late 1910's and early 1920's has already attracted detailed attention from historians of science Helge Kragh and Kristian H. Nielsen. They argue that the book, authored by Danish science writer and librarian Helge Holst in collaboration with Niels Bohr's former student and close colleague Hendrik A. Kramers,[3] not only attempted to make quantum theory comprehensible in non-technical language and visual images, but also highlighted Bohr's contribution to the development of quantum theory, thus celebrating Bohr as "a national hero of science."[4] Historians of science Arne Schirrmacher and Peter Bowler trace into the late 19th century public interest in new scientific ideas about matter and energy based on among other things the discovery of X-rays, radioactivity, and electrons.[5]

Other studies of popular physics books in the early 20th century include Michael Whitworth's analysis of books written by scientists, philosophers, and British science writer J. W. N. Sullivan, who in 1923 authored at least one book about atomic physics.[6] A historian of publishing, Whitworth examines sales numbers, prices, editions, and reviews, to conclude that, in effect, there were two distinct aspects of the popular demand for books dealing with the new

(2009), pp. 33-52 describes the "big picture books;" and Bensaude-Vincent (2001) mentions the increasing "conceptual gap." As Bell and Riesch (2013), p. 517 observe, the notion of popular science boom is difficult to qualify and may in fact "reflect little more than the consequence of publicity materials and/or nostalgically considered golden ages."

3. The book was orginally published in Danish (1922) and then translated into English (1923), German and Spanish (1923) and Dutch (1927), see Kragh and Nielsen (2013).

4. Kragh and Nielsen (2013), p. 283.

5. Bowler (2009), pp. 34-38; Schirrmacher (2007). Schirrmacher concludes that before 1919 relatively few articles published in Germany dealt with atomic structure. Bowler finds that most British authors publishing after 1920 fully embraced the new quantum theory, while just a few, such as Sir Oliver Lodge, who in his *Atoms and Rays* of 1924 indicated that quantum theory could not be the ultimate way in which to make sense of the new developments in atomic physics, propounded more cautious views.

6. Whitworth (1996).

physics of quantum theory and relativity. First, the books sold well. Second, the books made sure that the new physics became popular with the (educated) public by means of "straightforward expositions of the new physics ... [and] its wider implications."[7]

The popular "new physics books" appeared in a transformative phase of popular science when major developments in the publishing industry, the trade of journalism, and science were taking place. The increased interest in new theories of the atom, evidenced by the large number of popular books about atomic physics, was not only stimulated by rapid developments in quantum theory, but also by publishers' recognition of the books' potential sales and by the fact that some freelance journalists and independent writers were trying to make a living from popular science writing. Historians of science such as Bernard Lightman, James Secord, and Aileen Fyfe have shown that these developments emerged in Victorian Britain.[8] In Germany too, the field of popular science in print (and talk) expanded during the 19th century, not least as a result of an emerging bourgeois public sphere, accompanied by the expansion of the middle-classes, growing rates of literacy, accessibility of literature, and a new kind of critical journalism.[9] Throughout the early 20th century, the interest in reading about and discussing scientific ideas continued to expand (and so did the educated middle classes), and publishers, writers, and scientists proved to be more than willing to meet the demand.[10]

In the early 20th century, popular books about atomic physics were being supplied to expanding markets for scientific ideas in print in many European countries and in the United States. Even though these books all shared the same topic, the books were far from uniform. As we shall see, some framed quantum theory as a revolutionary and/or counterintuitive idea. Others were more cautious in expressing views with respect to the nature of quantum theory. Some used many metaphors to convey the basic ideas of

7. Whitworth (1996), pp. 57-58.

8. Fyfe (2004); Fyfe and Lightman (2007); Lightman (2007); Secord (2000).

9. Daum (2002); Schwarz (1999).

10. Bowler (2009); Broks (1996); Daum (2002); Schwarz (1999).

quantum theory to lay audiences with no or rudimentary mathematical skills. Others again more or less stuck to the mathematical descriptions, employing very little textual exposition. The use of visual imagery was very limited, which was probably due to the cost of printing images, and not to the lack of interest in visual depiction on the part of authors and publishers.

2. Popular "atomic books" as a discursive resource for scientists and others

The historical literature dealing with popular science is growing.[11] The very term popularization can be tricky as it sometimes is being used in a derogative way and sometimes to provide cultural legitimation for science proper. An important contribution from historians of science to the field of popular science, as Jonathan Topham has noted, is to historicize ideas about popular science:

> When and where did such notions originate? What ambiguities and complexities have they exhibited, and in what diverse and perhaps conflicting ways have they been used? How has their meaning and use changed over time, and what differences and continuities have their histories exhibited in different regions, countries, and languages?[12]

Surely, scientists and science writers have many reasons for engaging in the popularization of science. Most obviously or trivially, they want to make popular new scientific ideas. In a situation where there is controversy or discussion about new scientific ideas, they may also want to promote certain views or interpretations that for various reasons are not easy to communicate in the specialist literature.[13] Since quantum theory very much was in the making (and unmaking) in the historical period of our concern, it seems useful to think about popular books about atomic physics in this period as a

11. For recent reviews and discussions, see Topham et al. (2009).

12. Topham (2009).

13. Hilgartner (1990).

discursive resource for scientists and others, a kind of "interpretative retreat," as they grappled with new ways of understanding the constitution of matter.[14]

In the period from 1913 to ca. 1926, Bohr's atomic model was developed into the fully-fledged quantum theory, with the celebratory presentation in Bohr's Nobel Lecture in 1922 as one of its peaks. But soon thereafter it began to attract criticism, which eventually led to the conceptualization of quantum mechanics by Werner Heisenberg in 1925. The growing dissatisfaction with the old quantum theory in the scientific community from 1923 and onwards, partly due to the increasing number of anomalies faced, led to a gradual decline and ultimate dismissal of the theory by the end of the 1920s. Around 1920, most atomic physicists recognized that quantum theory had proven highly promising for future advances. Still, there was concern that quantum theory gave a less than adequate explanation of atomic structure, mainly because of the radical and uncertain nature of the quantum assumptions or postulates put forward by Bohr in his original contribution.[15]

Physicists and writers aspiring to popularize atomic physics around this time were faced with a number of challenges. As quantum theory was mostly expressed in mathematical notation and specialist language, they had to make decisions about the degree of textual exposition, i.e., the extent to which they wanted to translate quantum theory into everyday language. Also, questions relating to the epistemological uncertainties of quantum theory, in particular, the two quantum postulates made by Niels Bohr in his original articles, had to be tackled.[16] In what follows, the ways in which "quantum popularizers" in their books responded to such challenges of exposition will be addressed.[17]

14. Kragh and Nielsen (2013); Nikolow and Schirrmacher (2007).

15. Kragh (2012).

16. Bohr used the term "principal assumptions": 1. The transition between different stationary states cannot be treated on the basis of classical mechanics; 2. The transition is followed by the emission of homogenous radiation described by the equation $\Delta E=hv$, see Kragh (2012), pp. 61-62.

17. The sample of atomic books consists of eight books published between 1918 and 1924. It is a convenience sample as no effort has been made to survey more

3. Textual expositions of quantum theory

Exposing quantum theory to general audiences was not an easy task. Scientists were making rapid advances with new empirical and theoretical results appearing regularly. Bohr's atomic theory, first advanced in his three 1913 publications, was generally well received by the majority of physicists, many of whom contributed significantly to the development of quantum theory. Some of the most important contributions during the First World War were made by German physicists, especially Arnold Sommerfeld. In two important works dating from 1915-16, Sommerfeld developed Bohr's planar atomic model into a three-dimensional model governed by two, rather than just one, quantum number. In other words, the Rutherford-Bohr model of the hydrogen atom, where the negatively charged electron confined to an atomic shell encircles a small positively charged atomic nucleus, had given way to the Bohr-Sommerfeld atom with elliptical electron orbits that had quantized orientation in space and with relativistic variation in the mass of the electrons.[18]

Given the extent and importance of contributions from German physicists, it is perhaps unsurprising that the first popular books about quantum theory appeared on the German market. Leo Graetz, professor of physics in Munich, published six lectures about atomic theory in 1918 and, one year later, Arnold Sommerfeld published his *Atombau und Spektralinien*, which was also based on lectures held at the Ludwig Maximilian University of Munich.[19] Despite differences in scope – Graetz' book numbered just 88 pages while Sommerfeld's, in its first edition, contained 550 pages – the authors agreed that the new developments in atomic physics were in need of popular exposition. Graetz expressed his conviction that the topic of atomic theory would stimulate "general interest" amongst "most

systematically the market for books about quantum theory in this period. The purpose of this paper is not to provide an exhaustive survey of popular expositions of the Bohr atom, but rather to give a first insight into some of the rhetorical strategies employed by authors of such books.

18. Kragh (2012).

19. Graetz (1918); Sommerfeld (1919).

scientifically literate persons."[20] Sommerfeld was even more ambitious in presenting his book as aiming to be "generally understood" by "lay persons," which meant that the use of mathematics was kept at a fairly elementary level.[21]

3.1. The planetary model

Both Leo Graetz and Arnold Sommerfeld likened the new quantum atom to a miniature planetary system.[22] Graetz wrote: "Every atom consists of a positive electric nucleus of very small dimensions … . Around this positive nucleus, negative electrons move in circles (or as the case may be in elliptic orbits), just as planets move around the sun."[23] On the same page, he also mentioned the crucial difference between a real planetary system and the atom, namely that, whereas planets in principle were able to move around the sun in every possible orbit, electrons were only allowed to move in a fixed numbers of orbits defined by the square of integers: 1:4:9:16:25:36 etc. Sommerfeld compared the discrete orbits of "our atomic planet system" to those of the solar system.[24] In a footnote, he compared the quantum theory of the atom to the Titius-Bode law of the solar system, according to which the orbits of planets in the solar system follow a simple arithmetic rule of discrete numbers quite closely.[25] The analogy between the atomic planet system and the solar system also con-

20. Graetz (1918), preface.

21. Sommerfeld (1919), p. v. Kragh (2012), p. 153 has noted that the level of mathematical abstraction could only be seen as "elementary" according to Sommerfeld's own standards.

22. For excerpts of the pre-quantum theory history of planetary models in German magazines, see Schirrmacher (2007).

23. Graetz (1918), p. 71.

24. Sommerfeld (1919), p. 68.

25. The Titius-Bode law begins with the sequence 0, 3, 6, 12 etc., where each number after the 3 is double its predecessor. Then, add 4 to each and divide by 10 to arrive at 0.4, 0.7, 1.0, 1.6, 2.8, 5.2, 10.0, etc. To within 5% or so, these numbers correspond to the distances of the known planets at the time when expressed in astronomical units, the unit of the Earth's average distance from the Sun. Interestingly, the Titius-Bode law, which probably is nothing more than a numerical curiosity, predicted the distance of Uranus, Neptune and the dwarf planet Ceres, see Pickup (2012).

cerned the elliptical orbits, introduced into quantum theory by Sommerfeld:

> Just as in the solar system, the general movement of the electrons around the nucleus forms an ellipse, the focus of which is the nucleus, but these "Kepler ellipses" are only available in a limited and discrete number and, on the basis of quantum theoretical calculations, are arithmetically characterized by fixed eccentricities and major semiaxes.[26]

The planetary model, attractive as it was to some, but certainly not all authors of popular atomic books, was appealing in several ways. First of all, it offered ontological coherence by suggesting that the structures of the universe and the atom, respectively, were more or less identical. Moreover, it gave physicists and others a simple mental picture for comprehending the invisible. Finally, it provided a way in which to understand the rapid scientific changes of the time. Sir Oliver Lodge, British physicist, was very explicit about this latter connection between the discovery of the laws of motion of the universe and the discovery of the laws of motion of the atom. He wrote:

> To many of us it appears that we are certainly living in a Keplerian age: that is to say, in an age when all sorts of hypotheses are put forward, and are being compared with experiment and observation to see if they hold good, and even if their *rationale* is not at the time understood, and although they may have to wait, for full explanation, for the Newtonian age which in process of time ought to follow. Some of us have even suggested that a Newtonian age is beginning now; not because any one man is of the magnitude of Newton, but because there are so many men well equipped with mathematical methods of investigation, and standing on the shoulders of the great men of the past.[27]

26. Sommerfeld (1919), p. 68.
27. Lodge (1924), p. v.

3.2. Philosophical implications of quantum theory

Besides the two physics professors from Munich, Paul Kirchberger, a secondary school teacher from Charlottenburg, also published popular books in German about atomic theory.[28] Author of many books and articles about physics and astronomy, Kirchberger took a somewhat different approach from Leo Graetz and Arnold Sommerfeld. Kirchberger wanted to bring out the philosophical implications of the atomic theory. He explicitly aimed to address philosophically minded "spirits, who for epistemological-critical reasons are unable to understand that science performed by humans is able to make claims about dimensions that compare to the millimeter as the millimeter compares to the diameter of the earth."[29] Kirchberger stressed from the beginning that what the physicists were doing was seeking new answers to the enigma of the constitution of matter. How can we describe the existence of the table, he asked? Is the table somehow more than the sum of its parts? Is matter seen as being constant, continuous, or discrete?[30]

The philosophical speculations introduced by Kirchberger resonated with the book authored by British philosopher, mathematician, and science writer Bertrand Russell and published in 1923 (see also the introductory quote).[31] Like Kirchberger, Russell dwelt on the philosophical challenges of combining in a meaningful way quantum theory and everyday experience. Referring to the planetary model of the atom, Russell identified two kinds of discontinuities between the phenomenal world and the world of the quantum atom: "An atom," he wrote, "is found to be a sort of solar system, with sun and planets; the empty regions between the sun and the planets fill up vastly more space than they do, so that the greater part of the volume that seems to us to be filled by a solid body is really unoccupied."[32]

28. Kirchberger (1922a); Kirchberger (1922b).

29. Kirchberger (1922b), p. v.

30. Kirchberger (1922b), p. 1.

31. Russell (1923). At the time of writing, Russell earned a living as author of popular book about physics and many other topics, see for example Russell (1925) and Russell (1975), p. 152.

32. Russell (1923), p. 8.

Moreover, atomic processes are liable to sudden discontinuities or jumps from one state of continuous motion to another. How are we to reconcile this new view of discontinuous matter with the fact that things appear to us as "unbroken surfaces" obeying the old laws of dynamics, Russell asked? He provided one possible analogy as a way of answering this question, referring to a well-known cultural item, the cinema:

> There is a possibility that the old laws, which represented motion as a smooth continuous process, may be only statistical averages, and that, when we come down to a sufficiently minute scale, everything really proceeds by jumps, like the cinema, which produces a misleading appearance of continuous motion by means of a succession of separate pictures.[33]

3.3. What is the quantum?

Whereas Bertrand Russell exposed some of the counterintuitive implications of quantum theory, Oliver Lodge tried to familiarize his readers with the quantum by illustrating "the kind of discontinuity which the quantum represents."[34] He gave five examples based on everyday experiences:

1. A block or a pillar set up on a table can be upset by a critical force applied to it horizontally, but any force less than that need not cause any disturbance. The upset is a sudden or discontinuous result achieved by a definite force, and any force greater than the critical value can do no more than upset it.
2. Or take an explosive substance, say gunpowder. A spark of sufficient suddenness will ignite it and produce a violent result. A stronger spark will do no more, but an unsuitable spark of flame will do nothing.
3. Or take an example from agriculture. A seed thrown in the ground will germinate and produce a bush or tree of appropriate size. But half a seed would presumably decay and produce nothing. Indeed, seeds may be said to exist in quanta.

33. Russell (1923), p. 16.
34. Lodge (1924), p. 136.

4. Again, a clock gives the time in quanta. The hands of the clock do not move continuously, but in jerks.
5. The heavenly bodies are obviously discontinuous. There must be some reason, which indeed has been partly ascertained, why matter is distributed in the large masses that we call stars and not aggregated into one great lump by reason of gravitational attraction.[35]

From these examples, Lodge concluded:

> Some of the above illustrations may serve to show that there is nothing altogether novel and perturbing in the idea of physical discontinuities like quanta. And every example of their detection in unexplored regions of enquiry must be helpful and instructive, and contributory to further knowledge to a remarkable degree.[36]

3.4. Personification of the Bohr Atom

Bertrand Russell offered reconciliation between quantum theory and ordinary experience, making an attempt to personify the quantum atom. In explaining the process of radioactivity, he compared the nucleus to a family:

> The nucleus of any atom except hydrogen is a tight little system, which may be compared to a family of energetic people engaged in a perpetual family quarrel. In radio-activity some members of the family emigrate, and it is found that the energy they used to spend in quarrels at home is sufficient to govern an empire. If this source of energy can be utilized commercially, it will probably in time supersede every other.[37]

Russell too used personification in trying to explain the spontaneous and instantaneous jump from one stationary state to another: "An electron is like a man who, when he is insulted, listens at first apparently unmoved, and then suddenly hits out."[38]

35. Lodge (1924), pp. 136-137.
36. Lodge (1924), p. 138.
37. Russell (1923), p. 14.
38. Russell (1923), p. 63.

3.5. Acoustic models

Some authors gave acoustic analogies for the Bohr Atom. Oliver Lodge presented a rough illustrative mechanical model to explain the quantum constitution of the atom, the so-called staircase model: think of a marble rolling down a circular staircase, like a conical pyramid cut into steps. When it comes to the edge of a step, it tumbles over and acquires speed in its descent, so that it is moving more rapidly than before, but when it strikes, there is a noise and some of the energy is lost. If the marble was running round the steps in a sort of spiral, if the distance between the steps would increase from the top downwards, and if the marble could bounce over some of the steps, "then we would have a very rough and unsatisfactory model, but one which does suggest a discontinuous kind of fall, and also the emission of radiant energy in the form of sound or vibration every time there is an impact."[39]

Lodge also used another acoustic analogy to explain atomic spectra. Comparing the atom to "an assemblage of quiescent tuning-forks of different sizes," he presented the readers with the fact that atoms are only able to absorb certain frequencies of light just as tuning-forks only vibrate in tune with certain incoming sound waves. Moreover, when light of a specific frequency falls upon a specific atom, the atom also is able to fling away an electron, which, in the musical analogy, would amount to placing pellets in proximity to the tuning-forks and then having them being pushed away when they come into contact with the tuning-forks due to their vibration.[40]

The acoustic analogy and the staircase model propounded by Lodge were combined in the book authored by Helge Holst and Henrik A. Kramers.[41] They asked their readers to compare the atom with a hypothetical musical instrument consisting of a series of circular discs placed one above another, each disc being smaller than

39. Lodge (1924), pp. 133-134.

40. Lodge (1924), p. 65.

41. Holst and Kramers (1922); Kramers and Holst (1923). Note: Their book appeared in print before Lodge's.

the one below. A ball would move with no friction around any of the discs, corresponding to a system in a stationary state; it might then fall down to a lower disc, emitting a sound. Passing from one stationary state to another, the system would lose a quantity of energy equal to the work necessary to raise the ball again. The energy lost by moving from one state to another would be emitted as a sound from the instrument. If the smallest disc was grooved in such a way that the ball could fall no further, then "this fanciful instrument can provide a rough analogy with the Bohr atom. We must beware, however, of stretching the analogy farther than is here indicated."[42]

4. Many ways of popularizing the Bohr Atom

Oliver Lodge in his preface to *Atoms and Rays* deplored the fact that few scientists took the time to provide literary exposition of scientific discoveries.[43] He partly attributed scientists' lack of interest in popular science to their belief that "once a statement has been properly formulated there is no need of repetition, no need for full discussion and exposition of it in all its bearings." Lodge, however, saw things differently. He urged for multiple examination, discursive treatment, plentiful illustrations, books and essays and explanations and appreciations and criticisms innumerable, before any subject gets hold on the general mind.

Surely, fewer popular science books were appearing compared to popular books about culture (at any rate, this was Lodge's concern). Still, on the basis of the popular books surveyed in this paper it seems fair to conclude that quantum theory was indeed exposed to the kind of discursive treatment or literary exposition that Lodge wanted for all of science. Most books providing the kind of literary exposition that Lodge called for were printed in Great Britain. The three German books surveyed were rather technical and did not mention any analogies besides the planetary model. The British books were far more varied in terms of technicality, but also in their literary "clothing" of the Bohr Atom. If a reader in Great Britain

42. Kramers and Holst (1923), p. 120.

43. Lodge (1924), p. vi.

would have picked up all of the books mentioned, he or she would have been able to see the Bohr Atom as a planetary system, but also as different kinds of musical instruments, a staircase, and even an angry man. This imaginary reader would also have read about the nucleus as an energetic family prone to quarrels and break-ups, and he/she would have understood quantum discontinuities in terms of the cinema, as a block or a pillar set up on a table, an explosive substance, a seed, or a clock.

Some popular quantum books also went to some length to present some of the ontological and epistemological problems arising from the new quantum theory. Bertrand Russell, for example, started his book with a discussion of reconciling quantum theory with everyday experience (see the introductory quote), while Edward N. da C. Andrade explained that the acceptance of quantum theory amounted to relinquishing the idea of finding the absolute truth.[44] The justification for quantum theory lied in its success. Holst and Kramers, in their otherwise celebratory book, noted that quantum theory is "inconceivably far from being able to give a description of the atomic mechanism, such as would enable us to follow, for example, an electron from place to place during its entire motion, or to consider the stationary states as links in the whole instead of isolated 'gifts from above'."[45]

To summarize, the Bohr Atom as presented in popular science books had many facets. Depending on which book the casual reader would pick up, he or she would be presented with quite different literary expositions of the Bohr Atom and quantum theory. The level of mathematical abstraction ranged widely, with some books relying a great deal on mathematical expressions and calculations and others not containing a single formula. The structure of the atom would be described in more or less the same terms, using words like discontinuous, stationary states, jerks, quanta, and jumps, but the metaphors comparing the Bohr Atom to everyday experience would differ. The period from 1919 to ca. 1926 was characterized by many developments in science, but also a great deal of

44. Andrade (1923).
45. Kramers and Holst (1923), p. 132.

experimentation as regards the best ways to understand the new development in ordinary language. In the period, scientists, science writers, and publishers took advantage of the general interest in popular science that had been cultivated in many European countries and in the United States since the middle of the 19th century, marketing a broad range of ideas in relation to the new and fascinating quantum physics. More than simple promotion of well-established scientific theory, the popular atomic books represented honest attempts to communicate in ordinary language wide-ranging interpretations of some of the most counter-intuitive insights of physicists like Niels Bohr.

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