

LETTERS

More on the quantum measurement problem

Although I have neither an objection to nor an endorsement of David Mermin's major premise in his Quick Study, "There is no quantum measurement problem" (PHYSICS TODAY, June 2022, page 62), I would like to make several contextual points.

Mermin's argument has an extensive history, along with a comparable history of rebuttal. Five decades ago Max Jammer wrote that "measurements in quantum mechanics are no more or less problematic than in classical physics, for the Hilbert space vector is only a purely formal device for relating the statistics associated with these arrangements to the physics of observations in classical physics." That seems like a condensed version of the argument Mermin presents. On the following page, however, Jammer notes

that a "problematic aspect whose serious implications were only gradually understood was the fact that as long as a quantum mechanical one-body or many-body system does not interact with macroscopic objects, as long as its motion is described by the deterministic Schrödinger time-dependent equation, no events could be considered to take place in the system."¹

Regarding the quotations from Niels Bohr, Mermin's point is entirely valid and represents Bohr's position accurately, but Bohr's thought is always subtle and difficult to capture completely. Another quotation from Bohr, which is consistent with everything else he wrote, is, "The decisive point is that in neither case does the appropriate widening of our conceptual framework imply any appeal to the observing subject, which would hinder

unambiguous communication of experience."² That quotation seems inconsistent with Mermin's paragraph that includes the passage "Why should I insist that *my* interpretation of science, which I use to make sense of the world that I experience, should never make any mention of *me*?" Bohr always insisted that his framework was a rational "generalization" of classical objectivity.

The last and most conceptually important point concerns the ontological status of probability. I don't necessarily disagree with Mermin and Bruno de Finetti, but it is by no means obvious that they are correct either. David Hawkins, for example, begins 50 pages of rigorous analysis with a brief statement of a major premise.

The obvious and natural interpretation of probability in this context is that it introduces, not something that has to do with the nature of the physical system, but something that has to do with the incompleteness of our knowledge. . . .

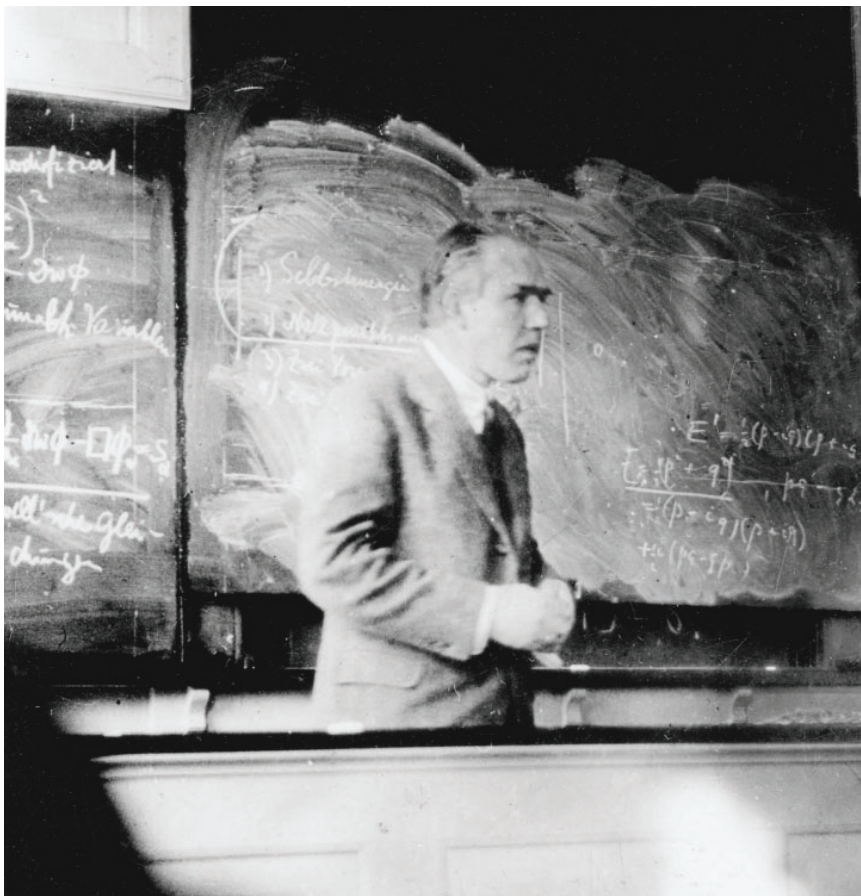
But this opinion turns out to be false. Ignorance of dynamical regularity may be a *motive* for resorting to probabilities, but it does not explain the probabilities to which we resort.³

Another example can be found in Jammer's well-known historical account of quantum theory: "For Einstein the notion of probability . . . was the traditional conception of classical physics, a mathematical objectivization of the human deficiency of complete or exact knowledge but ultimately a creation of the human mind. . . . For Born probability, as far as it was related to the wave function, was not merely a mathematical fiction but something endowed with physical reality."⁴

Of course, such examples don't mean that Mermin's position is incorrect, but I do think that they demand a better argument than a comparison to "Fairies and Witches." I am confident that Mermin has such an argument, and I look forward to reading it as I continue working toward a coherent position on the unresolved interpretational issues of quantum theory.

References

1. M. Jammer, *The Philosophy of Quantum Mechanics: The Interpretations of Quantum Mechanics in Historical Perspective*, Wiley (1974), pp. 473, 474.



NIELS BOHR giving a lecture in Copenhagen in April 1929. (Photograph by Samuel Goudsmit, courtesy of the AIP Emilio Segrè Visual Archives, Goudsmit Collection.)

2. N. Bohr, *Essays 1958–1962 on Atomic Physics and Human Knowledge*, Ox Bow Press (1987), p. 7.
3. D. Hawkins, *The Language of Nature: An Essay in the Philosophy of Science*, W. H. Freeman (1964), p. 135.
4. M. Jammer, *The Conceptual Development of Quantum Mechanics*, McGraw-Hill (1966), p. 286.

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In his June 2022 Quick Study (page 62), David Mermin argues that “the quantum state of a system expresses only the belief of the particular physicist who assigns it to the system.” Applying that to quantum measurements, he finds that “the acquisition of further information by that physicist . . . can lead to an abrupt change in those probabilities and thus to an updating of the quantum state that the physicist uses to represent them. There is no quantum measurement problem.”

But wavefunctions have been collapsing ever since the Big Bang, with no assistance from physicists. An apparatus’s display of a measurement outcome occurs even if the experimenters happen to be out of the room. When a cosmic-ray proton strikes a sand grain on Mars and moves the grain, a quantum measurement occurs and the proton’s wavefunction collapses regardless of the absence of humans.

Roger Carpenter and Andrew Anderson of the University of Cambridge performed a “Schrödinger’s cat” experiment that demolishes Mermin’s interpretation. Instead of connecting a Geiger counter to a cat-killing device, they mercifully connected it to a hammer that would fall without harm. Their strategy was to split information about the experimental result between two observers in such a way that neither observer can know the outcome. The observers learn the outcome later by sharing their information. The question is then, Did the hammer fall at the time of the experiment or later, when the observers became conscious of the outcome? The result: The hammer fell when the nucleus decayed, not later when the observers became conscious of the outcome. I think nearly all physicists would have pre-

dicted that. My hat is off to Carpenter and Anderson, who reported it with a straight face.¹

Humans and their consciousness have nothing to do with quantum physics. Photons, electrons, and the like, as well as their states, are real configurations of fields that have existed throughout the universe since the Big Bang.²

Nevertheless, I agree with Mermin’s title: There is no quantum measurement problem, because quantum physics, with no special interpretation and without a collapse postulate, logically implies that superpositions collapse nonlocally to a single definite outcome.³

References

1. R. H. S. Carpenter, A. J. Anderson, *Ann. Fond. Louis de Broglie* **31**, 45 (2006).
2. A. Hobson, *Am. J. Phys.* **81**, 211 (2013).
3. A. Hobson, *Quantum Eng.* **2022**, 5889159 (2022).

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Sean Carroll’s July Quick Study, “Addressing the quantum measurement problem” (page 62), brings up the following question: Does the wavefunction still obey the Schrödinger equation when a measurement is made? A system being measured (or interacting with its environment in any other way) is actually a subsystem, and a subsystem is properly described by a reduced density matrix. The density matrix for an entire system corresponds to a wavefunction—that is, to a pure state—but the density matrix for a subsystem does not necessarily correspond to a wavefunction. The reduced density matrix of a subsystem may correspond to an impure state, also called a mixture or an incoherent combination,¹ which does not have well-defined pure-state content.² In the words of Kurt Gottfried and Tung-Mow Yan, “systems in the real world are rarely in pure states.”³

The proper way to discuss a measurement is not using a wavefunction but rather a reduced density matrix. The density matrix of a pure state evolves according to the Liouville–von Neumann equation, which is equivalent to the unitary evolution of the wavefunction by the

time-dependent Schrödinger equation. For a subsystem (that is, for any system except the entire universe), the reduced density matrix evolves according to the nonunitary Liouville–von Neumann equation, which has an additional contribution causing decoherence and dissipation.⁴ The nature of the measurement—or, more generally, the nature of the subsystem–environment interaction—selects a preferred basis, called the pointer basis, and the subsystem decoheres into an effectively classical mixture in the pointer basis. (See the article by Wojciech Zurek, *PHYSICS TODAY*, October 1991, page 36.)

References

1. A. Bohm, *Quantum Mechanics: Foundations and Applications*, 3rd ed., Springer (1993), p. 72.
2. See, for example, L. E. Ballentine, *Quantum Mechanics: A Modern Development*, 2nd ed., World Scientific (2015), chap. 2.
3. K. Gottfried, T.-M. Yan, *Quantum Mechanics: Fundamentals*, 2nd ed., Springer (2003), p. 46.
4. See, for example, D. A. Micha, *Int. J. Quantum Chem.* **80**, 394 (2000).

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Among Art Hobson’s and Gregory Derry’s letters and Sean Carroll’s July Quick Study (page 62), only Derry’s letter addresses the point I was trying to make in my June Quick Study (page 62): Viewing probabilities as personal judgments eliminates the quantum measurement problem and enables one to make better sense of quantum mechanics.

Hobson’s letter expounds his own realistic view of quantum states and their collapse. It belongs with the three examples I mention that eliminate the physicist from the story.

Carroll takes what I write about the consequences of a personalist interpretation of *probability* to be an example of an epistemic interpretation of *quantum mechanics*. That misses my point.

In 1926 Max Born noted that the content of quantum states was the probabilities that they enabled one to calculate. It is strange that after thus elevating probability to a new and foundational role, no physicists then or for the next