# QUANTUM MEASUREMENTS

Art Hobson

Citation: American Journal of Physics **85**, 5 (2017); doi: 10.1119/1.4967925
View online: https://doi.org/10.1119/1.4967925
View Table of Contents: https://aapt.scitation.org/toc/ajp/85/1
Published by the American Association of Physics Teachers

**ARTICLES YOU MAY BE INTERESTED IN**

RICHARD FEYNMAN AND BELL'S THEOREM
American Journal of Physics **84**, 493 (2016); https://doi.org/10.1119/1.4948268

Entanglement isn't just for spin
American Journal of Physics **85**, 812 (2017); https://doi.org/10.1119/1.5003808

The geometry of relativity
American Journal of Physics **85**, 683 (2017); https://doi.org/10.1119/1.4997027

The Quantum Handshake: Entanglement, Nonlocality, and Transactions
American Journal of Physics **85**, 158 (2017); https://doi.org/10.1119/1.4966111

Gauge transformations and conserved quantities in classical and quantum mechanics
American Journal of Physics **84**, 616 (2016); https://doi.org/10.1119/1.4955153

AN APOLOGY FROM THE FORMER ASSOCIATE EDITOR
American Journal of Physics **85**, 405 (2017); https://doi.org/10.1119/1.4981790

# LETTERS TO THE EDITOR

*The downloaded PDF for any Letter in this section contains all the Letters in this section.*

Letters are selected for their expected interest for our readers. Some letters are sent to reviewers for advice; some are accepted or declined by the editor without review. Letters must be brief and may be edited, subject to the author's approval of significant changes. Although some comments on published articles and notes may be appropriate as letters, most such comments are reviewed according to a special procedure and appear, if accepted, in the Notes and Discussions section. (See the "Statement of Editorial Policy" at http://ajp.dickinson.edu/edPolicy.html.) Running controversies among letter writers will not be published.

## QUANTUM MEASUREMENTS

I congratulate Kincaid *et al*. on their recent article,[1] which nicely spells out the details of the measurement process for the important case of the double-slit experiment. I was impressed that the authors were able to carry out explicit calculations all the way through.

I agree entirely with the article's analysis, but it should be noted that the reduced state given in Eq. (11) is controversial among quantum foundations experts who debate the "quantum measurement problem," which is primarily the problem of how to think about the entangled post-measurement state of Eq. (7). If the detection apparatus $A$ is Schrodinger's cat in an arrangement designed to poison the cat when a radioactive nucleus decays, and if the quantum system $S$ is that nucleus, then Eq. (7) appears to be a superposition of a dead and alive cat, in contradiction with reality.

The reduced state Eq. (11) is criticized on at least three grounds.[2] First, it is said to be an "improper density operator" because it does not represent uncertainty about which state $S$ is in but is instead a reduction from the *known* pure state Eq. (7). Second, this reduced density operator is thought to be ambiguous because it has no "preferred basis"; it is simply 1/2 times the identity operator in $S$'s Hilbert space so that any basis of $S$'s Hilbert space forms a basis for this operator. Third, and most importantly, the pure state of Eq. (7) appears to be a state with no "definite outcomes" because it is a superposition, rather than a mixture, of two composite states (decayed nucleus/dead cat; undecayed nucleus/live cat) that themselves do represent definite outcomes so that the composite system $SA$ appears to be in both of these macroscopic states at the same time, implying that the two definite outcomes indicated by Eq. (11) must be spurious.

These criticisms have for decades led the quantum foundations community to reject analyses such as that of Kincaid *et al*., and to declare instead that the measurement problem has no resolution within standard quantum theory. The measurement problem is widely regarded as a stumbling block in the foundations of quantum physics.[3] This circumstance has led to a plethora of hypothesized alterations and reinterpretations of the theory, such as the GRW spontaneous collapse hypothesis,[4] the many-worlds interpretation,[5] and the de Broglie/Bohm pilot-wave theory.[6]

These criticisms have been leveled ever since Jauch's 1968 proposal that Eq. (11) actually does resolve the measurement problem since it says that, when $S$ and $A$ are in the composite state given by Eq. (7), a "local" observer of the nucleus alone must observe the nucleus to be either decayed or undecayed; thus, the expected conclusion (decayed or undecayed nucleus, dead or alive cat) cannot be inconsistent with Eq. (7).[7] These criticisms can all be answered within the framework of standard quantum physics, and in fact, nonlocal experiments with entangled photons demonstrate that Eq. (7) is non-problematic.[8] Nevertheless, these criticisms represent the consensus of the quantum foundations community, and should be noted in any analysis that derives the reduced state Eq. (11) from the composite state Eq. (7).

Art Hobson
*University of Arkansas Fayetteville, Arkansas* 72701

[1]J. Kincaid, K. McLelland, and M. Zwolak, "Measurement-induced decoherence and information in double-slit interference," Am J. Phys. **84**, 522–530 (2016).
[2]M. Schlosshauer, *Decoherence and the Quantum-to-Classical Transition* (Springer, Berlin, 2007).
[3]M. Schlosshauer, J. Kofler, and A. Zeilinger, "A snapshot of foundational attitudes toward quantum mechanics," Stud. Hist. Philos. Mod. Phys. **44**, 222–230 (2013); M. Schlosshauer, *Elegance and Enigma: The Quantum Interviews* (Springer, Berlin, 2011).
[4]G. Ghirardi, A. Rimini, and T. Weber, "Unified dynamics for microscopic and macroscopic systems," Phys. Rev. D **34**, 470–491 (1986).
[5]H. Everett, "Relative state formulation of quantum mechanics," Rev. Mod. Phys. **29**, 454–462 (1957).
[6]D. Bohm, "A suggested interpretation of the quantum theory in terms of 'hidden' variables, I and II," Phys. Rev. **85**, 166–193 (1952).
[7]J. Jauch, *Foundations of Quantum Mechanics* (Addison-Wesley, Reading, MA, 1968), pp. 183–191. For an especially clear presentation, see S. Rinner and E. K. Werner, "On the role of entanglement in Schrodinger's cat paradox," Cent. Eur. J. Phys. **6**, 178–183 (2008).
[8]A. Hobson, "Two-photon interferometry and quantum state collapse," Phys. Rev. A **88**, 022105 (2013); A. Hobson, "Resolving Schrodinger's cat," <http://arxiv.org/abs/1607.01298>.

## FEYNMAN AND BELL'S THEOREM, AND THE PRONUNCIATION OF "QUARK"

In his Letter to the Editor in the July 2016 issue of AJP,[1] Andrew Whitaker gives the wrong citation for the article that Richard Feynman wrote to me about in 1984. Whitaker's Ref. 13 should be to N. David Mermin, "Bringing home the atomic world: Quantum mysteries for anybody," Am. J. Phys. **49**, 940–943 (1981).

And in the November 2016 issue John Cramer, reviewing my new book of essays,[2] wonders why I chose to name the whole collection after the one on how to pronounce "quark." The reason is that, unlike Cramer, I regard it as the most amusing of the columns I published in *Physics Today* between 1988 and 2014. *De gustibus*.

N. David Mermin
*Cornell University, Ithaca, NY 14853-2501*

[1]A. Whitaker, "Richard Feynman and Bell's theorem," Am. J. Phys. **84**, 493–494 (2016).
[2]J. Cramer, "Why quark rhymes with pork, and other scientific diversions; by N. David Mermin," Am. J. Phys. **84**, 894–895 (2016).

 © 2017 American Association of Physics Teachers 