LETTERS TO THE EDITOR

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://www.kzoo.edu/ajp/docs/edpolicy.html.) Running controversies among letter writers will not be published.

COMMENT ON MERMIN'S REVIEW OF *QUANTUM ENIGMA* BY BRUCE ROSENBLUM AND FRED KUTTNER

I liked Rosenblum and Kuttner's (R&K) book *Quantum Enigma* and Mermin's review of it [Am. J. Phys. **75**(3), 287–288 (2007)], but I disagree with both in fundamental ways.

R&K's main contention, that conscious observation is required for a complete quantum measurement, is a groundless and unnecessary extravagance. For example, a photon making a permanent mark on a photographic plate is surely a quantum measurement, even if nobody is around to look at it. Once the mark is made, an observer can read it years later, or never, and the mark is still there in any case. To question the reality of such a mark is like questioning the reality of any other macroscopic object, such as the moon. It's an unnecessary extravagance to assume that consciousness is required.

The authors' answer seems to be that a human brain is needed because, when the photon makes its mark, the plate merely becomes entangled with the photon and this plate-plus-photon system must then be collapsed, and we get a "von Neumann chain" of such entangled but uncollapsed systems until, eventually, we reach a human brain which, according to R&K, collapses the entire series. But, brains are made of atoms too. Surely the series gets entangled with the brain, and so we have no solution to the problem. Furthermore, if brains are required to collapse quantum states, then I'd like to know if a low-IQ brain would do. How about a chimpanzee's brain? A worm's brain? Do wave packets not get collapsed on uninhabited planets?

Mermin rightly criticizes R&K's insistence on the centrality of consciousness, calling for a more balanced presentation. But, then he presents his own unnecessary extravagance, namely that quantum states are states of knowledge and not objective features of the systems they describe. This is surely a minority view.

Are we to assume that the states of a photon, or a hydrogen atom, exist only in our minds? What about states of a C_{60} molecule? A DNA molecule? A virus? Certainly quantum field theorists assume that field quanta such as photons and electrons and C_{60} molecules exist in the real world. Steven Weinberg states, for example, "In its mature form, the idea of quantum field theory is that quantum fields are the basic ingredients of the universe…."[1] I find it odd that neither R&K nor Mermin refer to our most basic theory of the microworld, quantum field theory, as they attempt to sort out the meaning of quantum physics.[1]

The essential ingredient in any resolution of the measurement problem, not mentioned by Mermin and barely mentioned by R&K, is surely the thermodynamically irreversible process that occurs between a quantum system and any macroscopic system (such as a measuring device) that the quantum system leaves a "macroscopic mark" on. Starting from this notion, the decoherence theory of Wojciech Zurek and others solves the von Neumann chain (or Schrödinger's cat, or classical-quantum boundary) problem. It's now known theoretically and experimentally that an interaction between a quantum system and its environment causes the environment to in effect monitor the system, very rapidly destroying the interference terms in the coherent entanglement between the system and the environment, and turning the entangled state into an incoherent state describable by a density operator in which only the probabilities of the preferred "pointer values" (eigenvalues) of the environment have predictive power. These probabilities are then classical and are no more mysterious than is the statement that there is an 0.5 probability of heads in a single coin toss. This situation was analyzed during the 1960s by several theorists, including Niels Bohr's longtime collaborator Leon Rosenfeld, who claimed that these conclusions are intuitively obvious and that Bohr had looked at quantum measurements in this manner.[2]

Nonrealistic and extravagant proposals, such as "consciousness collapses the wave packet" and "quantum states are states of knowledge," are no longer needed to resolve the measurement problem. It has been resolved within the realm of normal, realistic physics.

[1] Art Hobson, "Teaching quantum physics without paradoxes," The Physics Teacher **45**(2), 96–99, and references therein.

[2] Leon Rosenfeld, "The measuring process in quantum mechanics," Supplement (Commemoration Issue for the 30th Anniversary of the Meson Theory) to Prog. Theor. Phys. **34**, pp. 222–231 (1965); see also the reference therein.

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REVIEWER'S RESPONSE

My review of *Quantum Enigma: Physics Encounters Consciousness* mentions the idea that quantum states are states of knowledge not because I think that it currently provides all the answers, but because it was not among the many interpretations surveyed by

the authors, although it is an important one, going back to Heisenberg, and it undermines their argument that consciousness may affect physical phenomena.

My own attitude is sketched at the beginning of my review. Anybody reviewing a book on quantum foundations ought to declare at the outset the angle from which he currently regards that elephant. I do indeed believe that physicists often get into deep conceptual trouble by naively reifying too many of their abstract mathematical constructions. Among the overreifications I explicitly included quantum fields, through my reference to quantum electrodynamics. I did not mention decoherence as providing all the answers because I find its purported solution to many of the quantum enigmas to be among those John Bell memorably dismissed as FAPP (for all practical purposes) solutions.

Those who, with Art Hobson, take the apparently down-to-earth view that the polarization state of a photon is a real objective property of that photon, thereby commit themselves to the existence of real objective action at a distance. Taking quantum states to be real objective features of the systems they describe also entails the view that a 1000-Qbit quantum computer really carries out 10^{300} calculations in parallel. To me such conclusions are more extravagant than the notion that the quantum states of a physical system are powerful tools we have discovered to enable us to compute certain consequences of what we know about that system.

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AUTHOR'S RESPONSE

We are gratified that Art Hobson likes our book, *Quantum Enigma: Physics Encounters Consciousness*. But he misinterprets our display of physics' encounter with consciousness. What we claim for the encounter does not go beyond the quantum-theory-neutral experiments we describe. The outcomes of these experiments ("demonstrations" may be a better word since the outcomes are known) are completely undisputed. We invoke no quantum *theory* to establish physics' encounter with consciousness. We make no speculations of our own, beyond what can be displayed for anyone to see. We do go on to discuss nine currently contending interpretations of quantum theory and note how each of them deals with physics' encounter with consciousness.

Hobson insists that a measurement is made when, for example, a photon hits a photographic film (which is, presumably, in contact with the environment). But, is a measurement made when a photon hits a small, *isolated* piece of film? We can demonstrate that when the "piece of film" is *very* small, an isolated molecule perhaps, that the photon-molecule system goes into a superposition state, and thus *no* measurement is made. And quantum theory applies, in principle, to the large as well as the small. It's just hard to isolate a large object from the environment—and thus from conscious observers.

Hobson invokes "decoherence theory" as "in effect" resolving the enigma posed by the encounter with consciousness. In *effect*, yes. But this is so only for all *practical* purposes (something John Bell abbreviated as FAPP and warned against falling into the FAPPTRAP of thinking that such a treatment resolves the enigma). Zurek's major treatment of decoherence, for example, recognizes that, "An exhaustive answer to this question [the perception of a unique reality, i.e., a measurement] would undoubtedly have to involve a model of 'consciousness'…"[1]

We're delighted with all the nice things David Mermin says about our book in his review. His "major reservation" is that we exaggerate the role of consciousness but notes that, "Opinions range all over the map." We would say that we *emphasize* the role. Mermin's review faults us for not mentioning, among the nine interpretations we do describe, "the view that quantum states are states of knowledge and not objective features of the systems they describe." If quantum theory is about "knowledge," doesn't that hint of consciousness? But we agree with Mermin that this is an important view in light of its applicability to the burgeoning field of quantum computation, and it deserves treatment in the next edition of our book. A more detailed response to Mermin's review is on our book's website: www.quantumenigma.com

[1] W. H. Zurek, "Preferred states, predictability, classicality, and the environment-induced decoherence," Prog. Theor. Phys. **89**(2), 281 (1993).

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