Commentary: Quantum mechanics: Fixing the shifty split

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Citation: Physics Today **65**, 7, 8 (2012); doi: 10.1063/PT.3.1618
View online: https://doi.org/10.1063/PT.3.1618
View Table of Contents: http://physicstoday.scitation.org/toc/pto/65/7
Published by the American Institute of Physics

Commentary

Quantum mechanics: Fixing the shifty split

Quantum mechanics is the most useful and powerful theory physicists have ever devised. Yet today, nearly 90 years after its formulation, disagreement about the meaning of the theory is stronger than ever. New interpretations appear every year. None ever disappear.

Probability theory is considerably older than quantum mechanics and has also been plagued from the beginning by questions about its meaning. And quantum mechanics is inherently and famously probabilistic.

For the past decade, Carl Caves, Chris Fuchs, and Ruediger Schack have been arguing that the confusion at the foundations of quantum mechanics arises out of a confusion, prevalent among physicists, about the nature of probability.[1] They maintain that if probability is properly understood, the notorious quantum paradoxes either vanish or assume less vexing forms.

Most physicists have a frequentist view of probability: Probabilities describe objective properties of ensembles of "identically prepared" systems. Caves, Fuchs, and Schack take a personalist Bayesian view: An agent assigns a probability p to a single event as a measure of her belief that the event will take place.[2]

Such an agent is willing to pay less than \$$p$ for a coupon that will pay her \$1 if the event happens, and she is willing to underwrite and sell such a coupon for more than \$$p$. Surprisingly, the standard rules for probability follow from the requirement that an agent should never face certain loss in a single event. (For example, if p exceeded 1, she would pay more than \$1 for a coupon that returned at most \$1; if p were negative, she would pay somebody to take a coupon from her that might cost her another \$1.) Avoiding certain loss is the only constraint on an agent's probability assignments.

The probability of an event is not inherent in that event. Different agents, with different beliefs, will in general assign different probabilities to the same event.

The personalist Bayesian view of probability is widely held,[3] though not by many physicists. It has profound implications for the meaning of quantum mechanics, which Fuchs and Schack call quantum Bayesianism—QBism for short. Since quantum states determine probabilities, if probabilities are indeed assigned by an agent to express her degree of belief, then the quantum state of a physical system is not inherent in that system but assigned by an agent to encapsulate her beliefs about it. State assignments, like probabilities, are relative to an agent.

QBism immediately disposes of the paradox of "Wigner's friend." The friend makes a measurement in a closed laboratory, notes the outcome, and assigns a state corresponding to that outcome. Wigner, outside the door, doesn't know the outcome and assigns the friend, the apparatus, and the system an entangled state that superposes all possible outcomes. Who is right?

For the QBist, both are right: The friend assigns a state incorporating her experience; Wigner assigns a state incorporating his. Quantum state assignments, like probability assignments, are relative to the agent who makes them.

QBism also eliminates the notorious "measurement problem." Classical probability theory has no measurement problem: An agent unproblematically changes her probability assignments discontinuously when new experiences lead her to change her beliefs. It is just the same for her quantum state assignments. The change, in either case, is not in the physical system the agent is considering. Rather, it is in the probability or quantum state the agent chooses to encapsulate her expectations.

From the beginning, Werner Heisenberg and then Rudolf Peierls maintained that quantum states were not objective features of the world, but expressions of our knowledge. John Bell tellingly asked, "Whose knowledge? Knowledge about what?" The QBist makes a small but profound correction: Replace "knowledge" with "belief." Whose belief? The belief of the agent who makes the state assignment, informed by her past experience. Belief about what? About the content of her subsequent experience.

Bell also deplored a "shifty split" that haunts quantum mechanics. The shiftiness applies both to the nature of the split and to where it resides. The split can be between the quantum and the classical, the microscopic and the macroscopic, the reversible and the irreversible, the unspeakable (which requires the quantum formalism for its expression) and the speakable (which can be said in ordinary language). In all cases the boundary is moveable in either direction, up to an ill-defined point. Regardless of what is split from what, all versions of the shifty split are vague and ambiguous.

For the QBist, there is also a split. It is between the world in which an agent lives and her experience of that world. Shiftiness, vagueness, and ambiguity all arise from a failure to realize that like probabilities, like quantum states, like experience itself, the split belongs to an agent. All of them have their own split. What is macroscopic (classical, irreversible, speakable) for Alice can be microscopic (quantum, reversible, unspeakable) for Bob, whenever it is part of her experience but not his. Each split is between an object (the world) and a subject (an agent's irreducible awareness of her or his own experience). Setting aside dreams or hallucinations, I, as agent, have no trouble making such a distinction, and I assume that you don't either. Vagueness and ambiguity only arise if one fails to acknowledge that the splits reside not in the objective world, but at the boundaries between that world and the experiences of the various agents who use quantum mechanics.

Albert Einstein famously asked whether a wavefunction could be collapsed by the observations of a mouse. Bell expanded on that, asking whether the wavefunction of the world awaited the appearance of a physicist with a

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PhD before collapsing. The QBist answers both questions with "no." A mouse lacks the mental facility to use quantum mechanics to update its state assignments on the basis of its subsequent experience, but these days even an undergraduate can easily learn enough quantum mechanics to do just that.

QBism explains the persistence of the disreputable notion that "consciousness collapses the wavepacket." That is true, but in a banal way. The conscious experience of an agent guides her actions in any number of familiar ways. If she has at least an undergraduate degree in physics, these may include revising, on the basis of new experience, her expectations of future experience embodied in her prior quantum state assignments.

There are glimmerings of QBism in the writings of some of the founders of quantum mechanics. Niels Bohr wrote, "In our description of nature the purpose is not to disclose the real essence of the phenomena but only to track down, so far as it is possible, relations between the manifold aspects of our experience."[4] (Once I thought the crucial word here was "relations"; now I realize it is "experience.") Erwin Schrödinger, often philosophically at odds with Bohr, noted, "The scientist subconsciously, almost inadvertently simplifies his problem of understanding Nature by disregarding or cutting out of the picture to be constructed, himself, his own personality, the subject of cognizance."[5] (Here the crucial word is "subject.")

I find QBism by far the most interesting game in town. It has not, however, been enthusiastically received by the contemporary quantum-foundations community. Fuchs, in his role as QBism's most fervent advocate, is admired as a provocateur, his more technical work is highly regarded, and he was elected to the leadership of the American Physical Society's topical group on quantum information. But I would say that, with some important exceptions, the general response to QBism has been to shrug it off. I attribute that, in my uncharitable moments, to people having too much fun working on the puzzles that QBism has eliminated.

I write this Commentary not to persuade such experts, but to bring QBism to the attention of the much larger community of physicists who have no professional interest in quantum foundations. The message from QBism is this: You needn't feel guilty about never getting nervous about this stuff. You were right not to be bothered. But for the sake of intellectual coherence, you had better reexamine what you wrongly may have thought you understood perfectly well about the nature of probability.

References

1. See, for example, C. A. Fuchs, http://arxiv.org/abs/1003.5209, secs. 1–3.
2. For a short, readable introduction, see R. Jeffrey, *Subjective Probability: The Real Thing*, Cambridge U. Press, New York (2004).
3. J. M. Bernardo, A. F. M. Smith, *Bayesian Theory*, Wiley, New York (1994), and the 65 pages of references therein.
4. N. Bohr, *Collected Works*, vol. 6, J. Kalkar, ed., North-Holland, Amsterdam (1985), p. 296.
5. E. Schrödinger, *Nature and the Greeks, and Science and Humanism*, Cambridge U. Press, New York (1996), p. 92.

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Letters

Measured energy in Japan quake

The article by Thorne Lay and Hiroo Kanamori titled "Insights from the great 2011 Japan earthquake" (PHYSICS TODAY, December 2011, page 33) is an interesting one. As a seismologist who worked in the field of underground nuclear explosions, I was caught by the following statement in the first paragraph: "Total strain energy equivalent to a 100-megaton explosion was released during the sliding." Some familiarity with this subject led me to think this is not right. If the authors would carefully review their calculations using the energy equivalent in TNT, the relationship between seismic moment and magnitude, and the relationship between strain energy and seismic moment, they would find that the seismic energy equivalent of the 2011 Japan earthquake is roughly 2×10^{18} J, while that of a 100-megaton nuclear bomb is roughly 4×10^{17} J. Thus the 2011 Japan subduction event released approximately five times as much energy as a 100-megaton device, which is approximately twice the largest nuclear detonation ever—a 50-megaton atmospheric explosion by the former Soviet Union in October 1961.

The 1964 Chilean earthquake had still more energy by a factor of about 3, or 15 times that of a 100-megaton nuclear device. I believe the authors used the relation for seismic energy release rather than total strain energy release. The seismic energy underestimates the total strain energy release by a variable that depends on friction on the fault plane. Accounting for total strain energy release would increase the earthquake energy number by orders of magnitude.

Despite the catastrophic damage potential of nuclear bombs, the forces of nature occasionally unleash much larger energy releases. Although the nuclear bombs are under our control, earthquakes, volcanic eruptions, and extreme weather events are not. However, by judicious preparation and avoidance measures, humans can significantly diminish the damage of natural events.

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■ **Lay and Kanamori reply:** Our article states that the total radiated energy release estimated for the Tohoku event, as directly measured by integration of seismic-wave ground-velocity recordings and the source time function, is 4.2×10^{17} J. That number compares with David von Seggern's energy value for a 100-megaton explosion of "roughly 4×10^{17} J." Thus we seem to agree that our estimate of the seismic wave energy release from the earthquake corresponds to total energy from a 100-MT explosion.

The wording in the first paragraph of our article, however, should have been "total radiated energy" rather than "total strain energy." Some strain energy goes into heating the fault zone and other dissipative processes, so total strain energy will always exceed seismically radiated energy by an amount that cannot be measured by seismology. Von Seggern computes a number for "seismic energy" using a formula (apparently the Gutenberg–Richter relation) for radiated energy as a function of seismic magnitude; that is quite different from estimating radiated seismic energy directly as we did. His estimate of seismic energy is about a factor of five larger than our directly measured radiated energy estimate. Scaling relations between seismic magnitude and energy have very large spread, so we prefer direct measures of radiated energy from seismic waves.

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Private versus public energy solutions

Former Department of Energy official Steven Koonin expressed unwarranted confidence (PHYSICS TODAY, January 2012, page 19) that "energy needs to happen through the private sector. It owns, builds, operates essentially all the energy infrastructure in the country, and I don't think we have any intention of changing that."

I offer the following example to illustrate why I take issue with Koonin: During the night of 30 November–1 December 2011, residents of the West San Gabriel Valley, about 15 miles northeast of Los Angeles, experienced a severe Santa Ana windstorm that produced hurricane-force gusts. Thousands of trees were blown down, and power outages were widespread. The area is served by two utilities: Community-owned, not-for-profit Pasadena Water and Power (PWP), which provides electricity for the homes and businesses in Pasadena; and privately owned, for-profit Southern California Edison (SCE), which powers the surrounding communities.

Pasadena itself was probably the hardest hit, with about 1200 downed trees and nearly $30 million in damages. The wind speeds there during the event were at least as high as, and perhaps higher than, those in the surrounding communities. Nevertheless, only 10% of PWP customers lost power during the windstorm.

Meanwhile, Altadena, Arcadia, La Cañada Flintridge, and San Marino experienced total blackouts. In other nearby communities, such as Sierra Madre, South Pasadena, and Monrovia, at least 80% of homes and businesses lost power. In a front-page story in the *Pasadena Star-News* on 13 January 2012, SCE admitted that 75% of its customers in the area affected by the windstorm lost power.

In addition, while nearly all PWP customers had their power restored within 48 hours, many SCE customers had to wait much longer, some as long as a week.

The performance of SCE during and after the windstorm was so bad that it is now being investigated by the California Public Utilities Commission. Simply put, private-sector, for-profit SCE put in a dismal performance compared with the not-for-profit, community-owned PWP.

Perhaps Koonin needs to reconsider his belief that the private sector, with its focus on profits and stock dividends,