

Readers who want more details can contact me or consult the works cited in reference 4. I think it is high time we abolished antiquated approaches to teaching quantum theory along with the shifty split that confuses both students and their instructors.

References

1. J. S. Bell, *Speakable and Unsayable in Quantum Mechanics*, 2nd ed., Cambridge U. Press, New York (2004), chap. 23.
2. G. Birkhoff, J. von Neumann, *Ann. Math.* **37**, 823 (1936).
3. G. Bacciagaluppi, in *Handbook of Quantum Logic and Quantum Structures: Quantum Logic*, K. Engesser, D. M. Gabbay, D. Lehmann, eds., North-Holland, Amsterdam (2009), p. 49.
4. P. C. Hohenberg, *Rev. Mod. Phys.* **82**, 2835 (2010); R. B. Griffiths, *Consistent Quantum Theory*, Cambridge U. Press, New York (2002); R. B. Griffiths, *Found. Phys.* **41**, 705 (2011).
5. N. D. Mermin, *Pramana* **51**, 549 (1998).

Robert B. Griffiths

(rgrif@cmu.edu)

Carnegie Mellon University
Pittsburgh, Pennsylvania

■ **David Mermin's exposition** on QBism was excellent. However, it left the reconciliation between subjective and objective probability up in the air. There must be circumstances in which the subjective probabilities of different scientifically trained agents coincide, and hence the subjective and objective approaches also coincide. Quantum mechanics reminds us, if such a reminder is needed, that the human experiences that produce coinciding subjective probabilities, and hence interesting science, form a small subset of all human experiences.

Ching Hung Woo

Vista, California

■ **Some time ago**, John Bell and I wrote a tongue-in-cheek article on the interpretation of quantum mechanics;¹ in it we remarked that only a minority of physicists had any interest in the topic and that the typical physicist thought he would understand it "if ever he can spare twenty minutes to think about it." According to David Mermin, however, that situation has changed dramatically, and "new interpretations [of quantum mechanics] appear every year."

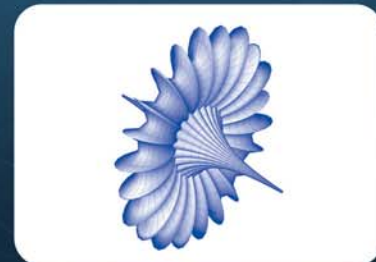
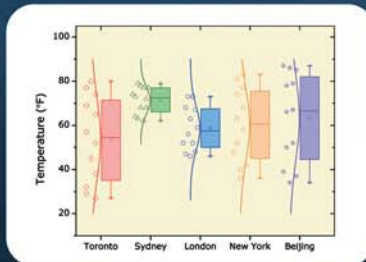
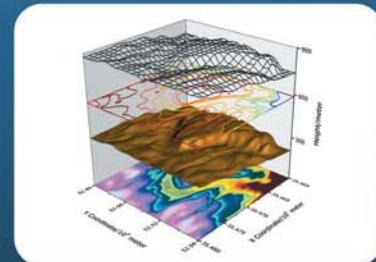
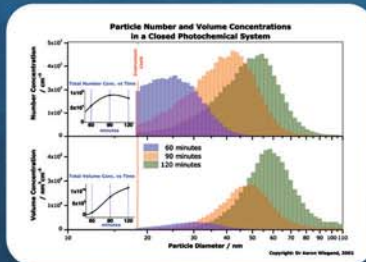
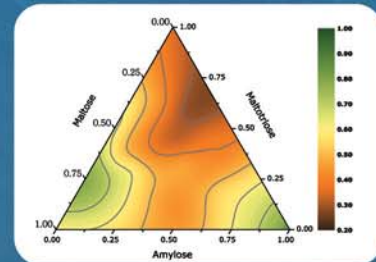
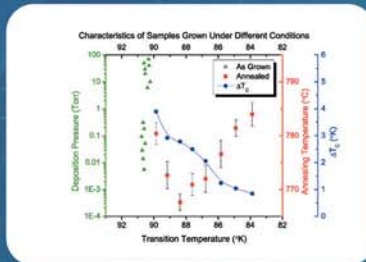
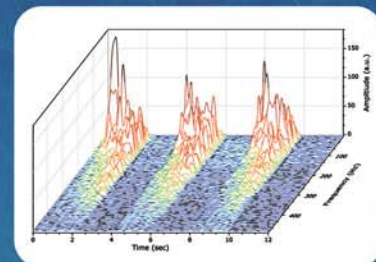
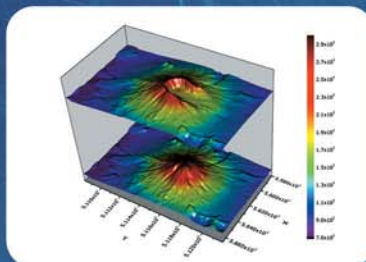
Actually, most textbooks on the subject continue to be based on the well-established Born interpretation of quantum mechanics, which postulates that the absolute square of the Schrödinger wavefunction, projected onto a particular quantum state, gives the



ORIGIN[®] 9

NEW VERSION

Data Analysis and Graphing Software. Powerful. Flexible. Easy to Use.



New features include:

- High-performance 3D Graphing using OpenGL
- 3D Parametric Function Plots
- Movie Creation
- Data Filter
- Floating Graphs in Worksheets
- Global Vertical Cursor
- Implicit Function Fitting
- IIR Filter Design

OriginLab[®]

For a complete product tour,
visit www.OriginLab.com/Physics

OriginLab Corporation
One Roundhouse Plaza
Northampton, MA 01060 USA

USA: (800) 969-7720
FAX: (413) 585-0126
EMAIL: sales@originlab.com

probability for the occurrence of that state after an appropriate measurement has been made. Mermin indicated that the problem with the Born interpretation involves a confusion, "prevalent among physicists," regarding the nature of probability. He presented his preference for a "personalist Bayesian view," which leads separate "agents," like Eugene Wigner and his friend, to make different probability assignments based on their beliefs. But as Richard Feynman remarked, "Nature does not know what you are looking at, and she behaves the way she is going to behave whether you bother to take down the data or not."²

Indeed, as applied to experiments, probability simply corresponds to the relative frequency for the occurrence of a given final state after identical states are prepared initially and measurements are made by appropriate detectors—devices that, through an irreversible macroscopic process, provide a permanent record of the outcome. Hence, the results of an experiment are independent of any observers, whose only role is to set up appropriate measurement devices, calculate the probabilities from quantum theory, and then write papers based on the recorded results.

As Max Born also emphasized, in classical mechanics the situation is analogous, when one takes into account that in practice initial conditions in an experiment are known only imprecisely.³ Hence the observed evolution of the system is also determined by a probability function that satisfies the Liouville equation. But in that case, after a measurement is performed, no one talks about the "collapse" of this classical function, whereas in quantum mechanics it is common to use that controversial expression for the Schrödinger wavefunction.

Mermin discussed a "shifty split" between the classical and the quantum domain, a split that supposedly "haunts quantum mechanics." He claimed that "regardless of what is split from what, all versions of the shifty split are vague and ambiguous." However, that is not always the case, as a simple example shows. Consider an initial quantum wavepacket for a particle under an attractive central force that varies inversely with the square of the radial distance—the classic problem of planetary motion from the viewpoint of quantum mechanics, for example, or an excited electron in a Rydberg atom. For a finite time, the wavepacket will follow

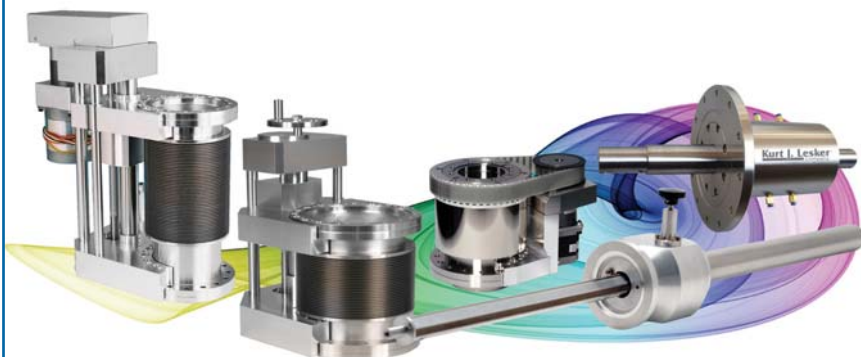
a classical Keplerian elliptic orbit, but like the Liouville distribution for the analogous classical problem, from the outset it will disperse due to the spread in initial position and momentum.

For the classical distribution to be in close correspondence with the quantum wavepacket, its initial spread is assumed to satisfy the uncertainty relation. Eventually, however, the head of the wavepacket, like in the classical distribution, will catch up with its tail. Afterwards, further spreading of the wavepacket leads to interference effects between the two components, and the classical–quantum correspondence ceases to be valid. The time when such interference effects first appear is of order $n\pi/3$, where n is the mean principal quantum number of the wavepacket and τ is the Kepler period.⁴ Experimentally, that transition has been observed to agree with theory in Rydberg atoms⁵ for $n = 100$, $\tau = 152$ picoseconds, and nothing shifty about this classical–quantum correspondence is found. For planetary orbits, however, n is of order 10^{20} , and therefore the answer to Albert Einstein's often repeated remark "Is the moon there when nobody looks?" (see David Mermin, *PHYSICS TODAY*, April 1985, page 38) is yes.

Kurt J. Lesker® Company

All Things Vacuum

Professional Vacuum Motion



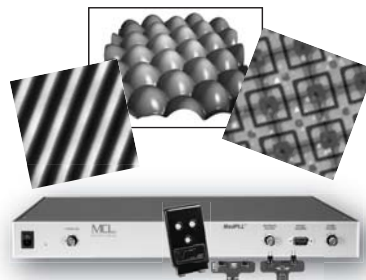
www.lesker.com

12-123

Introducing MadPLL™

Instant AFM and NSOM—just add science.

MadPLL™ includes software, digital PLL controller, probe and amplifier boards, and is fully compatible with Mad City Labs nanopositioning systems.



- Low cost imaging tool
- Automated control
- Integrated package
- Integrated z-axis control loop
- Suitable for resonant probes
- Build your own closed loop AFM!

MCL
MAD CITY LABS INC.

+1 608 298-0855
sales@madcitylabs.com
www.madcitylabs.com

References

1. J. S. Bell, M. Nauenberg, in *Preludes in Theoretical Physics*, A. de Shalit, H. Feshbach, L. van Hove, eds., North Holland, Amsterdam (1966), p. 270; reprinted in J. S. Bell, *Speakable and Unspeakable in Quantum Mechanics*, Cambridge U. Press, New York (1987), p. 24.
2. R. P. Feynman, R. B. Leighton, M. Sands, *The Feynman Lectures on Physics*, vol. 3, Addison-Wesley, Redwood City, CA (1989), p. 3-7.
3. M. Born, *Dan. Mat. Fys. Medd.* **30**(2), 1 (1955).
4. M. Nauenberg, *Phys. Rev. A* **40**, 1133 (1989).
5. M. Nauenberg, C. Stroud, J. Yeazell, *Sci. Am.*, June 1994, p. 44.

Michael Nauenberg
(michael@physics.ucsc.edu)
University of California
Santa Cruz

■ **Because it's important** that physicists discuss the problems of quantum foundations, I was delighted to see David Mermin's commentary on "fixing the shifty split." But I must disagree with my friend's view.

There are multiple ways of interpreting probabilities.¹ In quantum physics, the Bayesian "degree of belief" interpretation can be appropriate for mixed states, but only the frequentist or "ensemble" interpretation applies to the pure states that Mermin discusses.

A recent paper by Matthew Pusey and coauthors² concludes that if two different pure quantum states are assigned to a single physical situation, one of the states is objectively wrong. The proof's main assumption is that any quantum system has some set of real physical properties, labeled λ . Pusey and coauthors show that two different pure states cannot represent the same λ . So, although their paper implies but does not assume that quantum states are physically real, it does assume that each specific physical situation has behind it some kind of physical reality. Chris Fuchs, quoted favorably by Mermin, might dispute the notion that some kind of physical reality actually exists, but most physicists are probably sufficiently realist to grant that notion. Without such a notion, science lies somewhere between solipsism and superstition.

Whenever I hear subjective interpretations of quantum physics, I wonder about such questions as the one Mermin quotes from Albert Einstein: Can a mouse collapse a wavefunction? Mermin's Bayesian response, that a mouse cannot but a physics student can, doesn't reassure me. Were wavefunctions not collapsing before there were physicists?

The "Wigner's friend" paradox, as described in Mermin's commentary, doesn't need a subjective interpretation to find a solution. In fact, Eugene Wigner abandoned his interpretation around 1970 once he became aware of the ideas underlying quantum decoherence.³ Suppose Wigner's friend makes a measurement, the outcome of which is known to the friend but not to Wigner. Regardless of whether the outcome is known, and in fact regardless of the presence of the friend, the measurement device must decohere the quantum system that's being measured, putting the system into a mixed state of the either/or form, with no interferences, just like a coin that's been flipped. A definite outcome has thus occurred, and Wigner and his friend will both agree on this. Neither the friend nor Wigner affects the outcome. She has simply "looked" and now knows the outcome, while Wigner doesn't know. That is not paradoxical and does not require a revision of our understanding of pure quantum states.

There's no reason to give up on a realist interpretation of quantum physics, much less a realist interpretation of nature itself.

References

1. A. Hobson, *Concepts in Statistical Mechanics*, Gordon and Breach, New York (1971), p. 27.
2. M. F. Pusey, J. Barrett, T. Rudolph, <http://arxiv.org/abs/1111.3328v1>.
3. M. Schlosshauer, *Decoherence and the Quantum-to-Classical Transition*, Springer, Berlin (2007), p. 364.

Art Hobson
(ahobson@uark.edu)
University of Arkansas
Fayetteville

■ **David Mermin's essay** is a welcome introduction to the quantum Bayesian, or QBist, approach to quantum theory. Unfortunately, it stops just as the story gets interesting. The QBist research program is illuminating not just because it makes old philosophic problems melt away but because it nourishes new ideas that take root in the solid ground of everyday physics.

For example, the field of quantum-state tomography is concerned with how to acquire information about unknown quantum states. But if one holds, as the QBists do, that quantum states are states of knowledge, information, or—most provocatively—belief, what can it mean for a state of knowledge to be unknown? A subjective Bayesian classical statistician is in the same quandary when confronted with

Experiments in magnetic fields have never been so easy

Cryofree® magnet systems up to 18 T



Cryogen-free magnets up to 18 T, 10 T optical split and vector rotate now readily available

- Combined Cryofree low temperature/magnetic environment
- 1.5 K to 420 K with variable temperature insert
- Can be extended down to 25 mK with **Kelvinox®VT** dilution refrigerator
- Long run operation with our unique VTI design

For further information:
nanoscience@oxinst.com
www.oxinst.com/cryofreemagnets



The Business of Science®