the notion of an unknown probability. That problem was solved by Bruno de Finetti's representation theorem, which establishes that "unknown probability" is sloppy shorthand for a rigorously defined experimental scenario. Informally speaking, the classical de Finetti theorem says that if one is willing to gamble that the order of the repeated trials in a multi-trial experiment does not matter, then he can act as though he is measuring an "unknown probability." QBism resolves the conundrum of "unknown quantum states" with a quantum generalization of the de Finetti theorem. In turn, those developments, born from QBist philosophical inquiries, have led to practical advances in quantum tomography.[1]

Furthermore the QBist drive to understand quantum states as states of belief has stimulated fascinating technical work on the old problem of how to reexpress quantum mechanics entirely in terms of the probabilities that the states catalog. That work has led to advances in areas ranging from quantum information theory to the pure mathematics of Lie algebras.[2]

QBism treats measurement—the intervention of one piece of the natural world (the physical system) into the experience of another (the agent)—as a fundamental primitive process of quantum theory. Seeking a better definition of "measurement" from conventional pre-QBist quantum theory is rather like expecting the standard axioms of arithmetic to define the fundamental primitive terms "number," "zero," and "successor": an exercise in missing the point.

Some theorists treat quantum theory as a noncommuting generalization of classical probability.[3] Others think of it as overlapping with classical stochastic mechanics.[4] QBism takes quantum theory to be a specialization of unadorned probability theory, in which the restriction in question is imposed by the character of the physical world. If this variety of options does not say that today is an exciting time to study quantum probability, what could?

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■ **Mermin replies:** Robert Griffiths takes my joke about an undergraduate collapsing a wavepacket to be an attempt to solve the measurement problem. The actual QBist solution—versions of which predate QBism (see, for example, reference 1)—is that a quantum state is not an objective property of the world but a compendium of probabilities constructed by an agent. When an agent updates her state assignment, nothing changes in her external world. The only change is in the agent's expectations for her subsequent experience of that world, and therefore there is no measurement problem. Consistent historians agree that collapse is not a physical process, but for entirely different reasons.

QBism takes the "mysterious whatever-it-is" that Griffiths criticizes in quantum orthodoxy to be the experience induced in an agent by the world. That, and the fact that different agents may have different experiences, drains the swamp, slays the dragon, and quiets the maddening paradoxes.

QBists hold that any agent can indeed apply quantum mechanics to her own external world, from quarks to quasars. Only an agent's personal, directly perceived experience is boxed off from the domain of applicability. That exclusion disagrees with most versions of the many-worlds interpretation, but it does not limit the scope of science: Alice can apply quantum mechanics to the experience of another agent, Bob, as represented through his words, writings, or drawings, all of which do belong to her external world.

The way in which Bob's experience impinges on Alice resonates with Niels Bohr's emphasis on the need to state results of experiments in ordinary language. It also addresses Ching Hung Woo's question of how different agents can come to agreement on their state assignments.

Griffiths correctly notes that QBism violates the first desideratum he quotes from my 15-year-old "Ithaca interpretation." Like Barack Obama's view of marriage, my thinking about quantum foundations has evolved. But Griffiths wrongly claims that QBism rejects the other desideratum he quotes: locality. Actually, QBism insists on it. The absurdity of quantum nonlocality provides an independent argument that quantum states cannot be objective internal properties of the systems they describe, whether or not one regards probabilities as subjective. Griffiths is probably right, however, that John Bell would not have been pleased with how QBists fix his shifty split.

I would not call QBism an "antiquated approach." It is younger than Griffiths' consistent histories and, as I have remarked upon elsewhere,[2] taking reality itself to be relative to what he calls a framework, is vastly more radical than taking quantum state assignments to be relative to an agent.

But foreshadowings of QBism can indeed be found in antiquity. Since writing my commentary, I came across another striking anticipation in a 1931 letter from Erwin Schrödinger to Arnold Sommerfeld:[3] "Quantum mechanics forbids statements about what really exists—statements about the object. It deals only with the object–subject relation. Although this holds, after all, for any description of nature, it appears to hold in a much more radical and far-reaching sense in quantum mechanics" (translated by N. D. Mermin and Rudiger Schack).

When Bell and Michael Nauenberg wrote their delightful article in 1966, there was indeed much less interest in quantum foundations than there is today. Most textbooks have wisely steered clear of the many contemporary interpretive positions, since none of them are held by more than a fraction of those physicists with an interest in such issues.

QBists do not reject the Born rule for calculating probabilities, but they do reject the objective frequentist interpretation of those probabilities presented by Nauenberg and held by most physicists. The frequentist view is notoriously circular. It defines probability using such notions as "equally probable," "unlikely," or (with Nauenberg) "identically prepared," none of which make sense without a prior definition of probability. "Identically prepared" might seem safe from circularity, but two different preparations cannot be strictly identical. It would be more accurate to say they must differ in unimportant ways. Unimportant for what? For the probabilities of the outcomes.

When I started to learn about subjective probability, I was surprised to discover that most of the books were not in Cornell University's physics or mathematics libraries but in the business school library. In our recent election, Americans have been told that business experience is necessary for being president; I would suggest that it may be even more helpful for understanding quantum mechanics.

I cannot tell from Nauenberg's remarks about the Liouville equation whether he agrees with the view of QBists (and many others) that the collapse of the wavefunction is no more than the updating of a collection of probability distributions.

Nauenberg's example of the Rydberg atom does not contradict the QBist resolution of Bell's shifty split. The Rydberg atom is part of the world external to the agent, and therefore on the quantum side of her split. There are indeed circumstances under which fully quantum mechanical behavior can look very classical.

Art Hobson repeats the common view that only mixed states can be associated with subjective probabilities. QBism takes that to be the very mistake that got us lost for so long in the quantum swamp. Hobson also believes that wavefunctions were collapsing before there were physicists. Does he believe that probabilities were updating before there were statisticians?

Hobson wrongly claims that Chris Fuchs "might dispute the notion that some kind of physical reality actually exists." What he and other QBists do deny is that there are properties of the external world—"elements of reality"—that underlie quantum state assignments. (The argument of Matthew

Pusey and coauthors that Hobson cites, implying that quantum states are physically real, relies on such hidden variables.) An agent's state assignment rests entirely on her experience of the external world. It is neither solipsistic nor superstitious to maintain that any agent's experience comes fully into being only at the moment it is experienced.

Hobson's treatment of Eugene Wigner and his friend relies on decoherence producing an objective mixed state, which both of them must agree on. But since quantum mechanics holds all the way out to infinity (as Griffiths puts it), even from an objective view of quantum states, that switch from superposition to either/or is at best a FAPP solution, to use Bell's wonderfully sardonic abbreviation of "for all practical purposes."

QBism does not, as Hobson concludes, give up on a realist interpretation of nature. But it does warn us not to confuse nature with the abstractions we have ingeniously constructed to help any agent deal with the very real impact of nature on his or her own internal experience (see my Reference Frame, PHYSICS TODAY, May 2009, page 8).

I'm glad that Blake Stacey has called attention to some of the more applied spinoffs of QBism. I'm also pleased that he mentions Bruno de Finetti, one of the great 20th-century pioneers of subjective probability. Indeed, since there are objective as well as subjective Bayesians, if I had my way, the B in QBism would stand not for Thomas Bayes, but for Bruno de Finetti, who put the crucial point like this: "The abandonment of superstitious beliefs about the existence of Phlogiston, the Cosmic Ether, Absolute Space and Time . . . , or Fairies and Witches, was an essential step along the road to scientific thinking. Probability, too, if regarded as something endowed with some kind of objective existence, is no less a misleading misconception, an illusory attempt to

Open letter to the associate director for DOE's Office of Fusion Energy Sciences

We are early-career research scientists and professors, all under 40, who work in plasma and fusion science. We are concerned about the proposed fiscal year 2013 budget for the Office of Fusion Energy Sciences (OFES) in the Department of Energy's Office of Science and about the future plasma and fusion science funding trajectory it represents.

The current US administration has affirmed its "world-class commitment to science," with the goal of attracting more US students to science and engineering now, and to ITER, the international tokamak fusion project, as it reaches full operating capacity 15 years from now. Those commitments should be applauded, and they should be acted on sensibly to maximize the return on investment for US taxpayers in today's tough fiscal environment.

With a price tag upwards of $20 billion, ITER is the cornerstone of the world's fusion energy program. It represents a leap forward on the path to a viable fusion reactor. Yet ITER is more than an engineering project. It will have to create, confine, and control a self-sustained, burning plasma. The challenge of studying that plasma state is matched by the anticipation of what we will learn. We have theories of how a burning plasma will behave and how associated heat loads and energetic particles will impact the ITER wall materials. And there is one thing we know: ITER is discovery science, and a burning plasma will produce plenty of surprises once we get there. Some surprises may be advantageous, others will need to be mitigated.

US plasma and fusion scientists must be in a position to understand and expand on those new physics insights. The vibrant *domestic* program must be maintained and nurtured, so that today's graduate students and postdocs can become experienced scientists and leaders 15 years from now.

Instead, the administration's FY 2013 OFES budget redirects one-sixth of the FY 2012 domestic spending to the ITER project (see PHYSICS TODAY, June 2012, page 25). If that trend continues, within the next two years hundreds of scientists and engineers at premier US institutions will be laid off. Over time, those layoffs will lead to the permanent loss of some of the brightest young minds from the US plasma and fusion program, and likely from the academic and research communities altogether.

The fusion program has a public-image problem: It was supposed to deliver cheap and safe nuclear energy long before many of us young scientists entered the field. But the plasma and fusion program is much broader than energy research. It encompasses the study of supernovae explosions, solar coronal mass ejections, galaxy clusters, wakefield accelerators, the basic complexity of dynamical systems, and many other plasma phenomena.

Plasma science, with its enormous breadth, draws on many funding agencies, but the 2007 National Research Council report *Plasma Science: Advancing Knowledge in the National Interest* has called on the DOE Office of Science to take the stewardship role in guiding the multifaceted and exciting research field forward. The Office of Science must act on this deed of trust and enable us to capitalize on the public curiosity and interest in the 99.9% of the visible universe we call a plasma.

The US Congress has consistently said that ITER funding should not come from the domestic fusion program, which is already underfunded, yet the contributions to ITER are threatening to consume the entire domestic OFES-funded program. The proposed FY 2013 US contribution to ITER is $150 million and is scheduled to double or even triple in the next few years. That makes us deeply concerned for the ability of the Office of Science to allow and encourage domestic plasma and fusion research to survive and thrive.

The under-40 crowd, those expected to lead our field in the ITER era, respectfully request that you not let the world-leading US plasma and fusion program weaken in comparison to our partners and competitors. Instead, let us capitalize on the taxpayers' domestic R&D and ITER investments. Let us build a stronger and broader program to advance knowledge in basic plasma and fusion science and to prepare the scientific workforce of this country for the era of burning plasma.

In addition to the two of us, 61 other early-career scientists from 27 organizations across the country have signed this letter. The original version, with all its signatories, is available at http://fire.pppl.gov/under_40_letter_2012.pdf.

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exteriorize or materialize our [actual (*vero*)] probabilistic beliefs."[4]

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Delivering science to the public

David Kramer's Issues and Events item (Physics Today, July 2012, page 23) contains timely and important advice. It is far too easy for scientists to lay the blame for the public's overall discomfort with science on the early education system, the media, or political leaders. But in doing so, we miss an important component—that we, as scientists, have a responsibility to share our knowledge, not only with each other but with the general public. Communication must be a two-way street; scientists must work harder to improve and increase the dialog with nonscientists. As Kramer's article points out, scientists have an excellent vantage point from which to begin this process; the scientific community does hold a position of trust within the minds of the US public.

Although not all scientists have the interest or inclination to be the next scientific TV personality, smaller efforts can make positive changes. One such effort is a new project, Why-Sci (http://www.Why-Sci.com), funded by an American Physical Society Public Outreach Grant. Why-Sci is a website and forum that presents a rotating and expanding collection of snippets written by scientists for nonscientists. The site's offerings are short, straightforward, multipurpose descriptions of the what, how, and why of a research project accompanied by a single image. The snippets give the scientist experience in describing and communicating research to a nonscientific audience. For the nonscientist, they are an approachable introduction to a research project and its potential applications, and they offer an opportunity to connect with a real scientist.

During this time of difficult research funding—and defunding—choices, we scientists must step up to the plate and explain why what we do is fascinating, inspiring, and important, not just to us, but to society as a whole.

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■ **I wholeheartedly agree** with many of the points raised by David Kramer in his July 2012 article. As a science writer and communicator for more than 20 years, I have seen the enormous, not yet fully realized potential of scientists to convey the excitement and relevance of their research to the general public. Inside Science is a news service that is supported by the American Institute of Physics, numerous AIP member societies, and other STEM organizations. As its director, I help deliver news articles and video segments on scientists and their research.

Last year we introduced Inside Science Minds, an ongoing series of articles in which those in the science community speak directly to general audiences, whether to offer scientific perspectives on societal issues or to share new ideas. A year ago, I saw Nikodem Poplawski, a young theoretical physicist at Indiana University, present his explorations of the notion that our universe exists inside a black hole. I believed the idea would capture the imaginations of the general public while presenting some basic concepts in general relativity and quantum mechanics, so I invited Niko to write an article for us. After many months of working together to express his work in nonscientists' language, we posted the article (http://insidescience.org/?q=content/every-black-hole-contains-new-universe/566), which was immediately picked up online by Fox News and has become one of the most popular pieces on our website.

I welcome new article proposals for Inside Science Minds, and encourage Physics Today readers, their friends, and family members to check out the Inside Science website (http://www.insidescience.org).

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Correction

September 2012, page 68—The citation for Fang Lizhi and Li Shuxian's book *Creation of the Universe* is for the English translation. The Chinese edition was published by Science Press, Beijing, in 1987. ■