WHY I AM NOT A QBIST

Louis Marchildon

Department of
Chemistry, Biochemistry and Physics

UQTR
Université du Québec
à Trois-Rivières
Savoir. Surprendre.

INTRODUCTION

The *epistemic view* of quantum states, which goes back to Heisenberg, argues that the state vector represents information (or knowledge, or beliefs), rather than the true state of an actual physical system.

In the past two decades, the development of quantum information theory has brought the epistemic view back to the fore.

Quantum Bayesianism, or QBism for short, may be its sharpest formulation so far. [arXiv:1311.5253]

PHYSICS TODAY, MARCH 2000

OPINION

Quantum Theory Needs No 'Interpretation'

Christopher A. Fuchs and Asher Peres

Recently there has been a spate of articles, reviews, and letters in PHYSICS TODAY promoting various "interpretations" of quantum theory (see March 1998, page 42; April 1998, page 38; February 1999, page 11: July 1999, page 51; and August 1999, page 26). Their running theme is that from the time of quantum theory's emergence until the discovery of a particular interpretation, the theory was in a crisis because its foundations were unsatisfactory or even inconsistent. We are seriously concerned that the airing of these of our experimental activity, then we must be prepared for that, too.

The thread common to all the non-standard "interpretations" is the desire to create a new theory with features that correspond to some reality independent of our potential experiments. But, trying to fulfill a classical world-view by encumbering quantum mechanics with hidden variables, multiple worlds, consistency rules, or spontaneous collapse, without any improvement in its predictive power, only gives the illusion of a carry an umbrella. Probability theory is simply the quantitative formulation of how to make rational decisions in the face of uncertainty.

We do not deny the possible existence of an objective reality independent of what observers perceive. In particular, there is an "effective" reality in the limiting case of macroscopic phenomena like detector clicks or planetary motion: Any observer who happens to be present would acknowledge the objective occurrence of these events. However, such a macroscopic description ignores

QBISM IN A NUTSHELL

QBism views “quantum mechanics [as] a tool anyone can use to evaluate, on the basis of one’s past experience, one’s probabilistic expectations for one’s subsequent experience.”

- It explicitly adopts the subjective view of probability.
- Any agent can use quantum mechanics to model any physical system external to himself or herself.
- Once a specific outcome has occurred after interaction between the agent and a quantum system, the agent’s state vector is correspondingly updated.

In QBism, “quantum mechanics itself does not deal directly with the objective world; it deals with the experiences of that objective world that belong to whatever particular agent is making use of the quantum theory.”

QUANTUM MEASUREMENT PROBLEM

Question: How can a quantum system's state vector suddenly change upon measurement of a dynamical variable?

Answer: The collapse of the state vector simply reflects the acquisition of new beliefs by the agent.

NONLOCALITY

"QBist quantum mechanics is local because its entire purpose is to enable any single agent to organize her own degrees of belief about the contents of her own personal experience. No agent can move faster than light: the space-time trajectory of any agent is necessarily timelike. Her personal experience takes place along that trajectory."

PROTECTIVE MEASUREMENTS

Protective measurements yield the expectation value of any observable without appreciably changing the system's wave function.

$$
\begin{aligned}
H &= H_{\mathsf{S}} + H_{\mathsf{A}} + g(t)Q_{\mathsf{A}}O_{\mathsf{S}} \\
|\Phi(0)\rangle &= |\alpha(0)_{\mathsf{A}}\rangle|\Psi(0)_{\mathsf{S}}\rangle \\
[\Pi_{\mathsf{A}}, Q_{\mathsf{A}}] &= -i\hbar \\
[H_{\mathsf{A}}, \Pi_{\mathsf{A}}] &= 0
\end{aligned}
$$

Assume that H is such that $|\Psi_{\mathsf{S}}\rangle$ doesn't change much during measurement. For instance, $|\Psi_{\mathsf{S}}\rangle$ is initially an eigenstate of H_{S} and the interaction is much smaller than the difference in energy eigenstates.

Then by the adiabatic theorem

$$|\Phi(0)\rangle \to |\Phi(t)\rangle = |\alpha(t)_\mathsf{A}\rangle |\Psi(t)_\mathsf{S}\rangle$$

We have

$$\begin{aligned}\frac{d}{dt}\langle\Phi(t)|\Pi_\mathsf{A}|\Phi(t)\rangle &= \frac{1}{i\hbar}\langle\Phi(t)|[\Pi_\mathsf{A}, H]|\Phi(t)\rangle \\ &= \frac{1}{i\hbar}\langle\Phi(t)|(-i\hbar)g(t)O_\mathsf{S}|\Phi(t)\rangle \\ &= -g(t)\langle\Psi(t)_\mathsf{S}|O_\mathsf{S}|\Psi(t)_\mathsf{S}\rangle\end{aligned}$$

The expectation value of O_S is thus related to the observable change in the expectation value of Π_A. Knowledge of all expectation values allows reconstruction of the system's wave function.

PUSEY-BARRETT-RUDOLPH THEOREM

The argument assumes that (i) a quantum system has a real physical state (parametrized by λ) and that (ii) systems prepared independently have independent physical states.

Let $\mu_0(\lambda)$ be the distribution of physical states obtained under a quantum state preparation $|\psi_0\rangle$ (and similarly with $\mu_1(\lambda)$ and $|\psi_1\rangle$). If λ uniquely determines $|\psi\rangle$, the latter is *ontic*. Otherwise, if μ_0 and μ_1 overlap for some ψ_0 and ψ_1, the state vector is *epistemic*.

From their assumptions, PBR prove that epistemic state vectors are inconsistent with predictions of quantum mechanics.

Proof

Consider a two-state system with basis $|0\rangle$ and $|1\rangle$. Let

$$|+\rangle = \frac{1}{\sqrt{2}}(|0\rangle + |1\rangle)$$

and let μ_0 and μ_+ overlap, that is, there is a $\eta > 0$ such that when either $|0\rangle$ or $|+\rangle$ are prepared, there is a probability η that λ falls in the overlap.

Now consider two identical systems a and b that can both be prepared in either $|0\rangle$ or $|+\rangle$. There is a probability η^2 that λ_a is in the overlap of $\mu_0(\lambda_a)$ and $\mu_+(\lambda_a)$, and similarly with λ_b. Therefore there is a probability η^2 that (λ_a, λ_b) is compatible with any of $|00\rangle$, $|0+\rangle$, $|+0\rangle$ and $|++\rangle$.

Now bring the two systems together and measure an observable Ξ with orthonormal eigenvectors $|\xi_1\rangle$, $|\xi_2\rangle$, $|\xi_3\rangle$ and $|\xi_4\rangle$ such that

$$\langle \xi_1 | 00 \rangle = 0 \quad \langle \xi_2 | 0+ \rangle = 0 \quad \langle \xi_3 | +0 \rangle = 0 \quad \langle \xi_4 | ++ \rangle = 0$$

The measurement results depend only on (λ_a, λ_b). The apparatus doesn't know the preparation procedure. Hence in η^2 of the time, it runs the risk of finding a value incompatible with the preparation.

Now bring the two systems together and measure an observable Ξ with orthonormal eigenvectors $|\xi_1\rangle$, $|\xi_2\rangle$, $|\xi_3\rangle$ and $|\xi_4\rangle$ such that

$$\langle\xi_1|00\rangle = 0 \quad \langle\xi_2|0+\rangle = 0 \quad \langle\xi_3|+0\rangle = 0 \quad \langle\xi_4|++\rangle = 0$$

The measurement results depend only on (λ_a, λ_b). The apparatus doesn't know the preparation procedure. Hence in η^2 of the time, it runs the risk of finding a value incompatible with the preparation.

But Emerson *et al.* showed that the proof cannot be carried out if the PBR assumption $\mu_{\psi,\phi}(\lambda_a, \lambda_b) = \mu_\psi(\lambda_a)\mu_\phi(\lambda_b)$ is replaced by

$$\int_{\Lambda_s} \mu_{\psi,\phi}(\lambda_a, \lambda_b, \lambda_s)\, d\lambda_s = \mu_\psi(\lambda_a)\mu_\phi(\lambda_b)$$

where λ_s is a relational hidden variable.

TWO RELATED VIEWS

Philosophical *idealism* holds that only mind exists, and that matter is an illusion. An extreme form of idealism is *solipsism*, according to which only one mind exists.

Two reasons why idealism/solipsism may be attractive:

- The existence of my own mind is the only assertion I can be sure of. Everything else can be subject to doubt.
- Solipsism and idealism address and solve one the most profound philosophical questions, the mind-body problem.

Behaviorism claims that psychology should study the observable behavior of humans and animals, without introducing or using the concept of mental states. One of the objectives of psychology is then to predict the response of humans or animals to various kinds of stimuli.

RELATION WITH QBISM

QBism does not deny the existence of matter. But it does share an important methodological rule with idealistic philosophy: the only purpose of science is to organize an agent's (or a mind's) private experience.

For idealists:

Postulating the existence of matter makes no difference whatsoever to the mind's private experience. Matter is therefore regarded as superfluous.

For QBists:

Postulating true states for quantum particles makes no difference on an agent's beliefs and the probabilistic predictions he or she makes on that basis. Quantum particle states can therefore be considered as superfluous.

Mental states in behaviorism correspond to quantum particle states in QBism.

For behaviorists:

Relevant predictions can be made without having to consider the difficult question of the relationship between brain and mind.

For QBists:

Predictions can be made and optimal betting strategies can be developed without attributing states to quantum particles.

However, the analogy is not perfect. Behaviorists in general don't deny the existence of mental states. They just claim that they are irrelevant to psychology (while perhaps being relevant to something else). QBists, however, do in general deny the existence of quantum particle states, or at least their relevance to anything significant.

DISCUSSION

Two reasons to reject behaviorism:

- Personal preferences with regard to one's own mental states and their subjective importance.
- Empirical differences between predictions made on the basis of stimuli and responses only, and on the basis of introspection.

The empirical objection to behaviorism doesn't seem to apply to QBism. But this conclusion rests on a far-reaching hypothesis. It assumes that quantum mechanics is the ultimate theory of nature. This may be true, but it should be challenged, both on the experimental and theoretical sides. One theoretical challenge precisely consists in attributing states to quantum particles, and even hidden variables as in Bohmian mechanics.

Three reasons to reject idealism/solipsism:

- Our intuitive feeling for reality is too strong.
- We find it unbelievable that the order perceived in phenomena should be due to something solely in the mind.
- Even if there is nothing outside mind, we do not believe that our experience of other minds functioning, as it were, much like our own, could only be an artefact of our own unique mind.

These reasons have nothing to do with logical requirements or the results of experiments. In fact, they boil down to personal preferences.

How can an argument resting on personal preferences eventually move a QBist? Most QBists, while rejecting the objectivity of quantum states, believe in the existence of quantum particles. Then one can ask, "How can quantum particles be for quantum mechanics to be true?" I can see three broad types of answers to the above question. I claim that all three are interesting and relevant, even to QBists:

- There is a simple, coherent and intuitively appealing way to describe quantum particles that precisely yields the quantum formalism.

- There is no way that quantum particles can behave for quantum mechanics to be true.

- There are many ways quantum particles can behave for quantum mechanics to be true. But none has the cogency that the standard interpretation of classical mechanics has in terms of masses, positions and velocities of particles.

The fact that none of these answers is appealing to QBists leads many of them to do away with these approaches and stick to the experience of agents.

But for anyone who believes in the existence of quantum particles, that situation is problematic. How can one be comfortable with entities whose only known ways to behave are unbelievable? Doesn't this lead to look for other avenues and further think about the problem? If any known way by which quantum mechanics can be true raises problems, then *ipso facto* these problems transfer to QBism.

To conclude, QBism solves QM's foundational problems by declaring them to be outside the scope of science.

This criticism also applies to Mermin's solution to the problem of the Moving Now, where the experience of agents is the prime object of science, and space-time has no independent existence. But again one can ask, How can the constituents of the agent (atoms, molecules or cells), which have no Now experience, behave so that their aggregate has a Now experience?

See also arXiv:1403.1146.