What the Bleep Do We Know?[1]

Ulrich Mohrhoff

Sri Aurobindo International Centre of Education
Pondicherry 605002, India
ujm@auromail.net

The question "What the bleep do we know?" has an unambiguous answer: both surprisingly much and amazingly little.

Quantum mechanics, the theoretical framework of contemporary physics, is a probability algorithm. We use it to assign probabilities to possible measurement outcomes on the basis of actual measurement outcomes. While the (probabilistic) predictions of quantum mechanics are, as far as we know, always exactly right, they tell us amazingly little about the nature of Nature.

The problem of making physical sense of the mathematical formalism of quantum mechanics is known as the "measurement problem." With regard to this problem, the physics community is divided into three factions. The first advocates agnosticism. It asserts that the quantum world cannot be described; its features are forever beyond our ken. All we can usefully talk about is statistical correlations between measurement outcomes. The second faction aspires to describe the quantum world without reference to measurements. This faction is split into numerous warring sects. This is how physicist Christopher A. Fuchs describes the situation: "Go to any meeting devoted to some aspect of the quantum foundations, and it is like being in a holy city in great tumult. You will find all the religions with all their priests pitted in holy war—the Bohmians, the Consistent Historians, the Transactionalists, the Spontaneous Collapseans, the Einselectionists, the Contextual Objectivists, the outright Everettics, and many more beyond that... They all declare to see the light, the ultimate light..." The third faction—arguably the majority—is tired of this spectacle and no longer cares what (if anything) quantum mechanics is trying to tell us about the nature of Nature.

The agnostics have a point in that nothing of relevance can be said without reference to measurements. They are wrong in asserting that the features of the quantum world are beyond our ken. A great deal can be learned about its features by a careful examination of the quantum-mechanical probability assignments. The "priests" too have a point in that it is indeed possible to describe the features of the quantum world. They are wrong in their belief that these features can be described without reference to measurements. Instead of trying to understand the extraordinary role that measurements play in quantum mechanics, they aim to divest measurements of their special status. As a referee of a philosophy-of-science journal put it to me, "to solve [the measurement problem] means to design an interpretation in which measurement processes are not different in principle from ordinary physical interactions.''

There is another faction, a tiny one, whose members are rarely invited to a

[1] The title of this article is also the title of a recent movie that invokes features of the quantum world as well as misconceptions about quantum mechanics.

conference on quantum foundations, but which enjoys some popularity with ordinary folks. Physicists habitually refer to measurements as "observations." Observations presuppose observers. According to said faction, measurements owe their special status to the consciousness of the observer. I am not opposed to the idea as such. I am opposed to it because it makes it impossible to see the real ontological implication of quantum mechanics.

I have explored these implications in a number of publications.[2] Here is a very brief summary:

The most important consequence of the manner in which quantum mechanics assigns probabilities, is the existence of limits to the distinctions that we are allowed to make. Two examples:

1. Electrons are launched in front of a metal plate with two slits. After they have passed the slits, they hit a screen and leave a mark. If only the left slit is open, we see a certain distribution of marks. If only the right slit is open, we see another distribution of marks. If both slits are open, anyone uninitiated into the mysteries of the quantum world expects to see the sum of these two distributions. What we actually see is completely different. The electrons behave as if each went through both slits. Since this is the kind of behavior displayed by waves, electrons (as well as atoms, molecules, and bigger things) are often said to behave in "complementary" ways (a euphemism for mutually inconsistent ways of thinking): sometimes like particles (we never detect half an electron) and sometimes like waves.

If we do not remain satisfied with mutually inconsistent ways of thinking about one and the same thing, we discover that quantum mechanics imposes limits on our spatial distinctions. If there is no way of learning through which slit an electron went, the distinction we make between "the electron went through the left slit" and "the electron went through the right slit" is a distinction that Nature does not make. It corresponds to nothing in the physical world. It exists solely in our heads.

If we carry this implication to its logical conclusion, we discover an extraordinary fact: the spatial differentiation of the world is incomplete; it doesn't go all the way down. If we mentally partition the world into smaller and smaller regions, there comes a point when there isn't any material object left for which these regions, or the corresponding distinctions, exist. Much the same is true of the world's temporal differentiation: if we mentally divide the world's temporal extent into smaller and smaller intervals, there comes a point when the corresponding distinctions cease to have counterparts in the physical world. They exist solely in our heads.

2. Two particles of the same type move towards each other, one coming from the North, the other from the South. They "collide," and the next thing we know is that there

---

[2] Interested readers are invited to visit my website (www.ThisQuantumWorld.com) and/or consult my article "The Pondicherry interpretation of quantum mechanics: An overview." The latter appeared in PRAMANA (Vol. 64, February 2005, p. 171), the journal of physics of the Indian Academy of Sciences, and can be downloaded in several formats (I recommend PDF) from the preprint server at arxiv.org/abs/quant-ph/0412182.

are two particles moving away from each other, one eastward and one westward. Which is which? Is the particle moving eastward the one that came from the North or the one that came from the South? Once again the quantum-mechanical probability assignments imply that our question makes no sense. In asking it, we make an illegitimate substantial distinction. Quantum mechanics allows us to distinguish between *this* particle and *that* particle only to the extent that particles have properties by which they can be distinguished, and they have such properties only to the extent that their possession can be inferred from actual events or states of affairs ("measurements").

If we carry this implication to its logical conclusion, we discover another extraordinary fact: The so-called ultimate constituents of matter, *considered by themselves*, independently of their measured properties, are identical not just in the weak sense of exact similarity but in the strong sense of *numerical* identity. If you have a particle here with these properties and a particle there with those properties, what you have is not two substances each with a set of properties—this is one "two" too many—but one substance with two sets of properties.

What can we say of a structureless particle—a quark or an electron—*considered by itself*, out of relation to anything else? Since a structureless particle lacks internal relations, we cannot attribute to it a form. (All empirically accessible forms are sets of internal relations.) Out of relation to other objects, it lacks external relations, so we cannot attribute to it a position. (Positions are always defined in relation to each other.) Nor can we say that it moves, since motion, too, is relatively defined. So we cannot attribute to it any of the properties that derive their meanings from the quantum-mechanical description of motion. All we can say about a structureless particle considered by itself boils down to this: if it exists, then it exists!

The bottom line: What ultimately exists is a single substance. Call it whatever you like. (As a Vedantist, you might want to call it *brahman*.) Both matter and space come into being when this enters into spatial relations with itself, for space is the totality of existing spatial relations, while matter is the corresponding apparent multitude of relata—*apparent* because the relations are *self*-relations. The beasts and baubles of this world are not made of any kind of stuff; they are "made of" the self-relations of a single formless Reality. (As a Vedantist, you should be pleased: quantum mechanics affords us an insight into how *brahman* has made this world.)

* * *

So why do measurements play such an important role in quantum physics?

"Ordinary" objects have spatial extent (they "occupy" space), are composed of a (large but) finite number of objects without spatial extent (particles which do not occupy space), and are stable: they neither explode nor collapse the moment they are formed. Such an object occupies as much space as it does because atoms and molecules occupy as much space as they do. So how is it that an atom occupies a space roughly one tenth of a nanometer across? Thanks to quantum mechanics, we understand that the stability of matter rests on the *fuzziness* of the relative positions and momenta of its constituents. This is what "fluffs out" matter. The hydrogen atom is as big as it is because the position of the electron relative to the nucleus is as fuzzy as it is.

And what is the proper (mathematically rigorous and philosophically sound) way to describe a fuzzy position? It is to assign probabilities to the possible outcomes of position measurements! This is the principal (albeit not the only) reason why our fundamental physical theory is a probability algorithm, and why it refers to measurements.

Here is the real problem caused by the fact that measurements play this pivotal role: A fundamental physical theory concerned with nothing but statistical correlations between measurement outcomes presupposes outcome-indicating events. How can such a theory be complete? How can it at the same time *encompass* these events? Attempts to divest measurements of their special status sweep this problem under the rug without solving it. The solution calls for a judicious reality assignment: which feature of the quantum world—which theoretical construct of the quantum formalism—corresponds to what exists by itself, rather than by virtue of outcome-indicating events? The only possible answer: the macroworld (properly defined), in which the outcome-indicating events occur.

This makes three reasons why the quantum world is built "from the top down" rather than "from the bottom up." (i) The numerical identity of the so-called "ultimate constituents" of matter is inconsistent with the traditional attempt to construct reality by assembling a pre-existent multitude of building blocks. (ii) The fact that the quantum world is completely differentiated neither spacewise nor timewise, is inconsistent with the attempt to construct (a theoretical model of) reality on an intrinsically differentiated spacetime "manifold." (iii) The fact that the properties of the microworld exist only because, and only to the extent that, they are indicated by what happens or is the case in the macroworld, is inconsistent with the notion that the macroworld is made out of the ingredients of the microworld.

* * *

The presupposition of an intrinsically differentiated spacetime is all but universally shared by physicists and philosophers of science alike. Because it makes it impossible to realize the ontological implications of the quantum-mechanical probability algorithm, it has generated a variety of pseudoproblems and gratuitous solutions. The physics community appears to be irrevocably commited to the evolutionary paradigm—the notion that physics can be neatly divided into kinematics, which concerns the description of physical "systems" at any one time, and dynamics, which concerns the development ("evolution") of physical systems from earlier to later times—and this paradigm *entails* the existence of an intrinsically differentiated spacetime. The members of the second faction mentioned above—the "priests"—are unanimous in their belief that the quantum-mechanical wave function (or state vector) represents the actual state of the world at an instant of time, and that the quantum laws describe how this evolves. As a result, they are faced with the mother of all quantum-mechanical pseudoproblems: how is it that this instantaneous state has *two* modes of evolution?

As an algorithm for assigning probabilities to possible measurement outcomes on the basis of actual outcomes, the wave function has two obvious dependences. It depends continuously on the time of a measurement: if you change this time by a small amount, the probabilities assigned to the possible outcomes change by small amounts. And it depends discontinuously on the outcomes that constitute the assignment basis: if you take into account an outcome that you could not previously have taken into account, the assignment basis changes unpredictably as a matter of course. Transmogrify the wave function into the description of an evolving, instantaneous physical state, and you have to explain why it has (or appears to have) two modes of evolution rather than one: between measurements, it evolves continuously and predictably; at the time of a measurement, it evolves (or appears to evolve) discontinuously and unpredictably—it "collapses."

The most "compelling" reason for misconstruing the wave function as an evolving instantaneous physical state is that it permits us to believe in our own "omniscience," at least in principle: we know what exist, inasmuch as we have a complete mathematical description of the physical world at any one time, and we know how what exists behaves, inasmuch as we know the laws that govern its evolution. In the good old days of classical physics, we had algorithms for calculating the effects that material objects have on material objects, and it was possible, with a certain measure of consistency, to transmogrify these algorithms into a description of what exists and how this evolves. The attempt to transmogrify an algorithm for calculating the probabilities of measurement outcomes into a description of what exists and how this evolves produces nothing but absurdities (such as the "many worlds" extravaganza, to mention but one).

To the great Niels Bohr, this was obvious from the beginning. To lesser mortals, it ought to have been obvious ever since John Bell proved his two famous theorems, which led him to conclude that "there must be a mechanism whereby the setting of one measurement device can influence the reading of another instrument, however remote.'' Is there any hope of understanding this mechanism? Not if quantum mechanics is the fundamental theoretical framework that most physicists (including yours truly) believe it is. Since "fundamental" has no comparative, there *cannot* be a "more fundamental" theory that could explain the quantum-mechanical correlation laws. The explanatory buck stops right there.

To give you an idea of what is at stake, consider the following example due to Greenberger, Horne, and Zeilinger. Quantum mechanics makes it possible to condition three particles in such a way that the following correlations are observed: Whenever the x-components of the spins of the three particles are measured, the product of the results is -1. Whenever the y-components of the spins of any two particles and the x-component of the spin of the third particle are measured, the product of the outcomes is $+1$. (The possible results of each measurement are $+1$ and -1.) Is it possible that both the x-component and the y-component of the spin of each particle are in possession of values if these values are not actually measured? Suppose it is. If we call these values X_1, X_2, X_3 and Y_1, Y_2, Y_3, they must satisfy the following four equations:

$$X_1 \times Y_2 \times Y_3 = 1, \quad Y_1 \times X_2 \times Y_3 = 1, \quad Y_1 \times Y_2 \times X_3 = 1, \quad X_1 \times X_2 \times X_3 = -1.$$

Multiply the left-hand sides of the first three equations to find that their product equals $X_1 \times X_2 \times X_3 \times (Y_1)^2 \times (Y_2)^2 \times (Y_3)^2$. Since the squares of the Y's equal 1, and since the product of the right-hand sides of these three equations equals 1, these equations imply that $X_1 \times X_2 \times$

$X_3 = +1$. This obviously cannot be reconciled with the fourth equation. It is impossible to satisfy all four equations, and therefore it is impossible that both the x and y components of the spins of the three particles are in possession of unmeasured values. This illustrates that, in the quantum world, measurable quantities ("observables") have values only if and when they are measured. Measurements *create* their outcomes.

Observe that whenever the x components or the y components of two spins are measured, the outcome of a measurement of the x component of the third spin can be predicted with certainty. By the same token, whenever one x component and one y component are measured, the outcome of a measurement of the y component of the third spin can be predicted with certainty. How can we understand this given (i) that the values of the spin components are created as and when they are measured, (ii) that the relative times of the measurements are irrelevant, and (iii) that in principle the three particles can be millions of miles apart? How does the third spin "know" about the outcomes of the two other spin measurements? What mechanism correlates the outcomes? You understand this as much as anybody else!

If the outcomes of measurements performed on two or more physical systems are correlated, the systems are said to be "entangled." Entanglement is undoubtedly the most perplexing feature of the quantum world. Einstein spoke of "spooky actions at a distance" and hoped they would eventually go away. Nine years after Einstein's death, this hope was dashed by Bell. Spooky actions at a distance are here to stay. What is so unsettling is not that we cannot explain them; no fundamental theory can be explained by a "more fundamental" theory, and the transmogrification of a mathematical symbol into a physical entity has never been more than a sleight of hand. What is so unsettling is that they do not seem possible at all.

Given the manner in which the *perceived* world is constructed by our minds and/or brains, we naturally share Einstein's belief that "things claim an existence independent of one another" whenever they "lie in different parts of space." Fact is that those three particles, irrespective of the distances between them, are not independent of one another. Fiction is that they lie in different parts of space. Space is not something that has parts. It is a system of more or less fuzzy relations between formless particles. (If we insist on thinking of space instead as an expanse that exists independently of its material "content," quantum mechanics does not permit us to think of this expanse as divided. Instead of separating things, it unites things by its lack of parts.) Besides, all existing relations are self-relations—relations between *brahman* and *brahman*. This being so, how could things possibly "claim an existence independent of one another"?

I will conclude on a more personal note. The interpretation of the quantum formalism is a metaphysical and therefore to some extent a religious issue. The attempt to interpret the formalism in such a way that we can continue to believe in our "omniscience in principle" obviously plays into the hands of the materialists, which probably explains the relative popularity of this approach among theoretical physicists. But materialism is just one of many possible metaphysical stories, and it is not in any way more "scientific" than other stories that are consistent with the quantum-mechanical correlation laws.

The quality of our lives depends to a considerable extent on the metaphysical stories that most appeal to us. Such stories can dishearten as well as inspire. Although I will not deny it the aesthetic appeal of a Greek tragedy, I find the materialistic story depressing: in it, consciousness, free will, quality, and value play at best minor parts; evolution has no goal, life no real purpose; the paltry range of achievements offered to us is not worth mentioning.

Here is my favorite story: Ultimate reality is ineffable. Following a great tradition, I call it *brahman*. While there are no words to describe what *brahman* is in or by itself, we can say something about how it relates to the world. It relates to it in three ways: as the substance that constitutes it (*sat*), as the consciousness that contains it (*chit*), and as something—subjectively speaking, an infinite delight, objectively speaking, an infinite quality—that throws itself into finite forms and movements (*ananda*). Consciousness, free will, quality, and value all have their roots in what is ultimately real. At the roots of our consciousness is *chit*, at the roots of quality and value is *ananda*, at the roots of our free will is the infinite power by which *chit* creates its content, *sat* creates its forms, and *ananda* expresses itself.

Given an infinite and omnipotent quality and delight as the creative principle, there can be many differently constituted worlds—many ways of expressing and experiencing this quality and delight in self-relations. In the physical world, *brahman* is playing Houdini, imprisoning and enchaining itself as completely as divinely possible, challenging itself to escape, to re-discover itself, to realize its powers against formidable odds, in what appears to be a huge inert inconscient mass governed by mechanical forces and random events, but what is really the foundation of greatest stability and concreteness for a progressive self-realization that may go on for ever. The range of possible achievements offered to us by this story is infinite.

Turning once more to physics, recall that it is strictly impossible to account for the efficacy of fundamental laws, whatever they are. For the materialists, this is a serious problem, hence their (futile) attempts to render the fundamental laws self-sufficient by transmogrifying the mathematical formalism into a physical ontology. But if the force at work in the world is ultimately an omnipotent conscious force (*chit-tapas*), then this is not a problem at all. There obviously is no need to account for the efficacy of an omnipotent force! The question that then calls for attention is, why does this force subject itself to the quantum-mechanical correlation laws? And why these particular laws rather than any others? The answer: in order to set the stage for *brahman*'s adventure of evolution, and because this requires the validity of these very laws! (I am not claiming that my favorite story is corroborated by the fact that it entails the quantum laws. There may be many other stories that entail the same laws.[3])

3 See my paper "Why the laws of physics are just so" in Foundations of Physics, Vol. 32, 2002, p. 1313; quant-ph/0202149.