Quantum Puzzles

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The following is adapted from a fuller essay (tentatively entitled "Unfulfilled Revolution") scheduled for publication in The Nature Institute's online *NetFuture* newsletter. The essay originated as a commentary on *The New Physics and Cosmology: Dialogues with the Dalai Lama,* edited by Arthur Zajonc (Oxford: Oxford University Press, 2004).

By the beginning of the twentieth century, the paradigm of classical physics and cosmology, founded on mechanistic models, dominated not only the hard sciences, but also the life sciences. Further, since a mind that insists on contemplating the world in a mechanistic fashion forces itself to function mechanistically, it is no accident that the reigning paradigm was looking more and more attractive even as a framework for understanding the mind.

The early decades of the twentieth century shook this simple and comfortable world outlook with a disturbing force we have still barely begun to comprehend. It is hard, Arthur Zajonc writes, to overestimate the significance of quantum theory and relativity. These theories challenged mechanistic accounts of the cosmos and granted unexpected significance to the human observer. "The ramifications of twentieth-century discoveries for physics and cosmology have been enormous, changing our very notions of space and time, the ultimate nature of matter, and the evolution of the universe." The philosophical implications are, as Zajonc adds, "still being sorted out."

Or being ignored. The stance of our culture toward the revolution in physics is oddly schizophrenic. On the one hand, we have been treated, since at least the 1960s, to a parade of popularizations glorifying the counter-intuitive or bizarre results of what must seem to the layman an unapproachable science. These authors tell us of esoteric physicists in saffron robes, masters of zen and the tao, who from on high have stolen forbidden glimpses of the cosmic dance.

But little of this drama, and none of its real significance, seem to have penetrated the public's day-to-day consciousness of science. This is evident, above all, in the schools, where the pictures with which we saturate the imaginations of children—neat pictures of atoms and particles whirling in the void—are more representative of nineteenth-century mechanism than twentieth-century revolution. It seems at times that the awe-inspiring and incomprehensible wonders of the popularizers serve primarily to add a mystical or religious aura to the otherwise humdrum, soul-paralyzing dogma cluttering our minds in the name of science.

The thought habits of these past few hundred years are, it appears, deeply ingrained. How they might be transformed in accordance with the knowledge we now have, and whether the lay public can participate in the transforming conversations — or instead must be excluded because of the recondite subject matter—these are fascinating questions upon which *The New Physics and Cosmology* bears directly. For it documents the attempt by several contemporary physicists to convey some of the content of their discipline to the Dalai Lama and to engage this penetrating thinker in discussion of the scientific and philosophical issues raised. We are allowed, as it were, to learn along with the Tibetan monk, and to discover whether the conversation is one into which we, too, might enter.

Besides Zajonc, who is a professor of physics at Amherst College, our companions in this exercise include several other quantum physicists and cosmologists of note. For example, Piet Hut is a professor of astrophysics and interdisciplinary studies at the Institute for Advanced Study in Princeton. David Finkelstein is the long-time editor of the *International Journal of Theoretical Physics*. And Anton Zeilinger, formerly director of the Institute for Experimental Physics at the University of Innsbruck, Austria, is now a professor of physics at the University of Vienna.

In this article I do not discuss the contributions from the side of Buddhism, which I am unqualified to assess. I should add, however, that the Dalai Lama makes for an undeniably engaging conversational partner.

Particles and Waves

There is a crucial experiment in quantum physics called the "double-slit" or "two-hole" experiment. In the briefest of terms (and employing the common terminology): if you fire a narrow beam of photons at a screen with two small holes in it, the photons going through these holes will form an interference pattern on a second screen placed behind the holes.

This pattern, consisting of alternating light and dark bands, is exactly what you would expect if the photons were in fact waves passing through both holes at once and then interfering with each other. But at the same time—and this is the beginning of the mystery—each individual photon makes a discrete impact at a particular location, as if it were not a wave, but a particle.

Moreover, you can send the photons toward the holes one at a time, with each making a single flash on the screen (or spot of light on a photographic plate). In this case, as physicist John Gribbin explains,

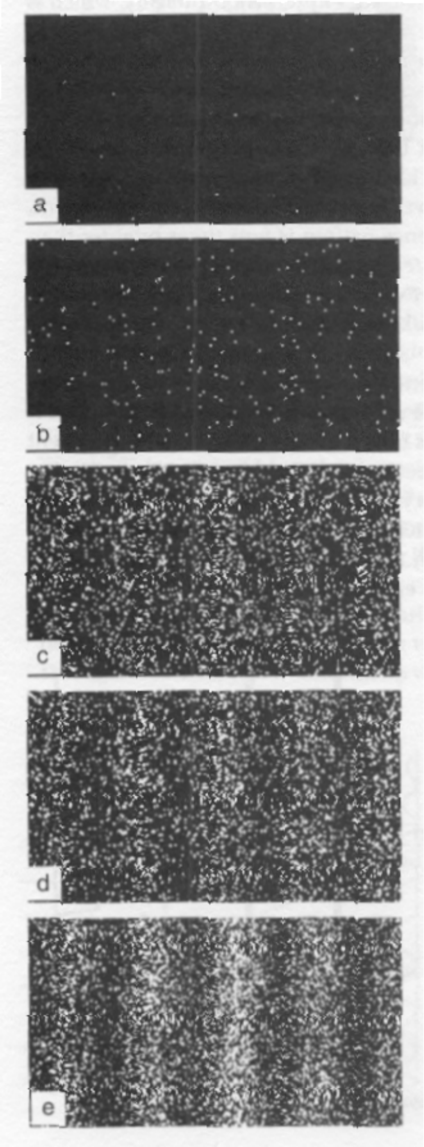
> "You might think that each particle must go through only one or the other of the two holes. But as more and more spots build up on the screen, the pattern that emerges is the classic interference pattern for waves passing through both holes at once. The quantum entities not only seem to be able to pass through both holes at once, but to have an awareness of past and future, so that each can 'choose' to make its own contribution to the interference pattern, in just the right place to build the pattern up...."

Gribbin goes on:

> There's more. If you think this is fishy, and set up a detector to tell you which hole each particle is going through, all of this mysterious behaviour disappears. Now, you do indeed see each particle ... going through just one hole, and you get two blobs of light on the detector screen, without interference. The quantum entities seem to know when you are watching them, and adjust their behaviour accordingly .... Each single quantum entity seems to know about the whole experimental set-up, including when and where the observer is choosing to monitor it, and about the past and future of the experiment" (Gribbin 2000, p. 113).

You will find the same behavior with electrons and, indeed (at least in principle), with every other particle or collection of particles. Calling this experiment the "central mystery" of quantum mechanics, Richard Feynman once remarked that it is "impossible, *absolutely* impossible, to explain in any classical way .... In reality, it contains the *only* mystery ... the basic peculiarities of *all* quantum mechanics" (Feynman, Leighton, and Sands, vol. 3, p. 1-1). Feynman was emphatic about this, later writing that

> any other situation in quantum mechanics, it turns out, can always be explained by saying, "You remember the case of the experiment with two holes? It's the same thing." (Feynman 1965, p. 130)



When electrons are fired one at a time through the two holes of the classic double-slit experiment, they progressively build up the interference pattern shown in these photographs from the Hitachi Research Laboratories. The pattern is like the one formed when a wave passes through two holes, whereupon the secondary waves issuing from the holes interfere with each other. However, each electron makes a single spot of light on the detector screen as if it followed a well-defined, particle-like trajectory through one hole or the other.

A common way of stating the puzzle runs something like this: If the electron is a particle, how does each one "know" where to land in order to build up the interference-like pattern? This seems to require that it "remember" where all the others have landed. On the other hand, if the electron is a wave, how does it manage to register an impact at a single spot? Another way of stating the puzzle: So far as any scientific determination of cause and effect is concerned, every individual electron impact is absolutely random. Yet the result of all the impacts is a non-random pattern. How can this be?

A Spirit of Inquiry

There is good reason to underscore this importance of the double-slit experiment since, as an observable phenomenon, it is not terribly difficult to grasp. It can easily be presented to high school students—and, most importantly, presented as a set of questions. Science could thereby become for the student a living inquiry rather than a logically systematized body of truth. If the stimulating questions posed by the "central mystery" of physics have not in fact become central to the public's consciousness of science, we can only assume a massive failure of education on the part of the scientific community. And a huge lost opportunity.

The counter-intuitive nature of the double-slit experiment is, after all, a reason *for* presenting it to the student, not a reason for avoiding it. Evidently our intuitions need re-educating. A science realistic in its self-appraisal might find in this a reason for modesty. One of the appealing aspects of *The New Physics and Cosmology* is that we encounter leading experimentalists and theoreticians who *have* gained from their work a sense of modesty. The phrase "we don't understand" is not foreign to these pages. When told that a certain answer might arrive in fifteen years, Anton Zeilinger responds,

> That has been said very often in the history of science: Come back in fifteen years. And the answer did not come; the problem just sounded more complicated. I remember people saying, "Give me one piece of the moon and I will tell you the history of the universe." It did not happen that way. We got one piece of the moon, but it turned out to be more complicated.

It is occasionally startling to hear these physicists expressing themselves, not only as scientists, but also as human beings. David Finkelstein suggests that "far from being strangers in the universe, we are actually part of the law that governs it, and we help make the law that determines our own lives." And he continues:

> Things like love and meaning are presumably not there under the microscope. But we shouldn't be surprised that we don't find them there because they are behind us in the home from which we come.

Likewise, Piet Hut, noting that science "cannot say anything yet about the original raw experience" upon which it is based, predicts that "the next relativity theory ... will include a relativity between the object and the subject, between the physical and the mental." He confesses, "I cannot jump yet. I am a little bit too scared to make such a big jump." Yet he can recognize in "the Tibetan notion of the sameness of outer and inner space ... something very similar to what I expect to happen in the language of science in the next hundred years or so."

Contradictions

Unfortunately, the spirit of openness and dialogue evident in this book is not always present within science as a whole. A tendency toward compartmental isolation and rigidity of thought mars what would otherwise be an endlessly stimulating intellectual landscape. How is it, for example, that reputable physicists can posit consciousness as a fundamental category—or even as the ultimate source of reality—yet in the other sciences (which strain so hard toward the authoritative aura of physics) any suggestion that consciousness is primary and irreducible remains taboo? Apparently the authority being honored derives from the physics of yesterday, not the knowledge and open-ended inquiry of the leading thinkers in physics today.

Similarly, we live in a time when Feynman can say of quantum mechanics, "how does it really work? What machinery is actually producing this thing? Nobody knows any machinery" (1965, p. 145). In fact, if there is one thing quantum mechanics seems intrinsically unable to present us with, it is anything remotely resembling machinery. And yet, too many smug scientists, trusting to a bottom-up, material-building-block view of the world, somehow manage to overlook the absence of mechanical building blocks at the bottom as they speak confidently of the triumph of mechanism. Thus, Harvard biologist E. O. Wilson casually remarks that "People, after all, are just extremely complicated machines." And in the words of robotics expert Rodney Brooks, "The body, this mass of biomolecules, is a machine that acts according to a set of specifiable rules .... We are machines, as are our spouses, our children, and our dogs...."

One wonders how these commentators have managed to avoid the entire history of twentieth-century physics. But it turns out that ignoring what one prefers not to look at is almost a defining characteristic of much science today.

Fruitful Ambiguities

A great deal of misunderstanding about the significance of physics arises from confusion over the notion of explanation. Physicists unanimously assure us—and rightly so—that quantum mechanics provides methods of remarkable universality. No phenomenon has ever been encountered for which these methods of analysis and statistical prediction do not work. This leads researchers to say, "As far as we can tell, there is no experiment that quantum theory does not explain, at least in principle" (Herbert 1985, p. 44).

That is fine, but we need to recognize the extreme narrowness and shallowness characterizing this particular notion of "explanation." After all, from another standpoint we can say that quantum theory explains almost nothing. It does not, for example, explain the red color I see—or, for that matter, any of the observable, sensible reality science was originally intended to explain. This experiential realm (which is in fact the only realm we have) has mostly been set aside and bracketed as lying outside science proper. So when Piet Hut imagines a science that can mediate "between the object and the subject, between the physical and the mental," he is imagining a revolution that will dwarf anything the twentieth-century has seen. One appreciates his fear of making the leap. Explaining an observed phenomenon—if we ever begin to make the attempt—will radically differ from merely identifying certain quantitative and statistical regularities abstracted from it. (See "Do Physical Laws Make Things Happen?" available at http://qual.natureinstitute.org.)

One way to picture the limitations of today's science is by imagining a logical-mathematical grid laid over the world. The quantitative perfection of our explanations can then be seen as a function of the infinitesimal thinness and precision of the grid lines. But because of this same thinness, we can also say that the phenomena we are viewing almost completely escape the grid, falling between the lines. And if we thicken the lines so as to "cover" more of the phenomena, we find that their precision disappears. The grid's logical and numerical "joints," so to speak, are no longer exact; with thick lines, we can no longer specify precise and unambiguous points where the lines cross.

There is, in other words, a trade-off between a kind of universal precision that treats certain mathematical features of phenomena but leaves the phenomena themselves unaccounted for, on the one hand, and, on the other hand, a more adequate reckoning with the phenomena—a reckoning, however, that sacrifices the rigidity and narrow precision of the logical grid. The Chinese scholar, Tu Weiming, hinted at this when he remarked to the Dalai Lama and other symposium participants, "It is [the] ability to appreciate fruitful ambiguities, rather than to search for that which is true and certain in a limited sense, that opens up all kinds of new possibilities."

Polar Opposites

The truth underlying Weiming's remark is widely under-appreciated today. It is the truth of a polar opposition between meaning and accuracy, or between depth of insight and the ease of articulating and conveying that insight (Barfield 1967, pp. 35ff.; Barfield 1973). The scientist and policymaker, Warren Weaver, alluded to this opposition when he wrote,

> One has the vague feeling that [mathematically defined] information and meaning may prove to be something like a pair of canonically conjugate variables in quantum theory, they being subject to some joint restriction that condemns a person to the sacrifice of the one as he insists on having much of the other. (Shannon and Weaver 1963, p. 28)

Weaver's comment occurred in an introduction to *The Mathematical Theory of Communication*—a treatise explicitly stating that "the semantic [meaningful] aspects of communication are irrelevant to the engineering aspects." The treatise, of course, is about the engineering aspects. This decision to ignore meaning in the pursuit of quantitative exactness—a decision widespread throughout science—makes it obvious why physicists have been brought to the point where an understanding of the character of reality seems unreachable. Their explanatory "grid" simply leaves too much of the world out of sight.

All this makes two salient facts of contemporary physics wholly compatible:

> We have a precisely formulated quantum mechanics of seemingly perfect and universal applicability.
>
> We have physicists proposing various understandings of reality that are as wildly imaginative, outrageous, diverse, bizarre, and mutually contradictory as any of the proposals ventured by medieval metaphysicians.

On this last point you need only consider the debates over questions such as the following: Are the world's laws founded upon absolute randomness? Does reality consist of a steadily increasing number of parallel universes? Can time flow backward? Are there "wormholes" that take a shortcut through spacetime, linking two different times? Is there a shadow universe sharing gravity, but no other forces, with our own universe? Can we know the real world at all? Does observation create reality? Does consciousness create reality?

Such questions are posed by some of the same physicists who assure us they are closing in upon a "final theory of everything"! "Everything" in this case seems perilously close to "nothing"—just as a grid of universal extent and absolutely precise lines "covers" everything and nothing at all.

The extraordinary narrowness of much scientific explanation—especially in the hardest sciences—seems lost on most scientists. The undeniable satisfactions of precision and of successful quantitative prediction blind them to the fact that they have, with their unambiguous theories, largely abandoned the world we actually observe. This is why questions about reality or the meaning of quantum mechanics lead so quickly to unrestrained metaphysical fantasy. There is not enough reality in the parameters of this science to constrain interpretation. Without a reversal of four hundred years of scientific history—without a willingness to transform a science of quantities alone into a science of phenomena—one can only remain pessimistic in the face of Zajonc's expressed hope that

> the fluctuations of concepts and opinions only indicate a violent process of transformation which in the end will lead to something better than the mess of formulas that today surrounds our subject.

The New Physics and Cosmology itself does not attempt to point the way toward a qualitative science. But at least it gives us reason to think there might be an openness to such a science among those researchers who have confronted most dramatically the unexpected boundaries of the science we now have.

A final note. In my judgment, the book does not fully succeed in its effort to present key aspects of modern physics to the layman. It proceeds too quickly from sketchy descriptions of scientific experiments to a discussion of their meaning. It would be wonderful to have a book that more thoroughly presented the experiments, developing the philosophical issues in a closer and more detailed relation to those experiments—a book less wide-ranging in speculative coverage, perhaps, but more revealing of the science. Nevertheless, the discussion we are given in this book is full of rewarding insights and surprises.

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