The Emperor's New Swindle

Detlef Dürr, Sheldon Goldstein, Roderich Tumulka & Nino Zanghi are uncovering the great quantum con trick.

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by JULIE REHMEYER

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"I felt like God must have felt when He created the world."

It's a bold statement, but if Detlef Dürr's calculations are correct, he has every reason to be proud. He and his colleagues, Sheldon Goldstein, Nino Zanghi, and Roderich Tumulka are rewriting the foundations of physics—demystifying quantum mechanics by removing its paradoxes and the indeterminacy that lies at its heart.

Quantum mechanics is a fantastically successful theory. There's just one small problem—it's crazy. The list of quantum paradoxes seems endless: Electrons and other fundamental particles have a schizophrenic nature, sometimes acting like waves and sometimes behaving like particles. Quantum objects can be in two places at once and have multiple, mutually contradictory properties. Common sense quails at Schrödinger's cat that is somehow both alive and dead at the same time. And you cannot predict the outcome of a quantum experiment with certainty, only the probability of getting a certain result—God appears to be playing dice with the universe.

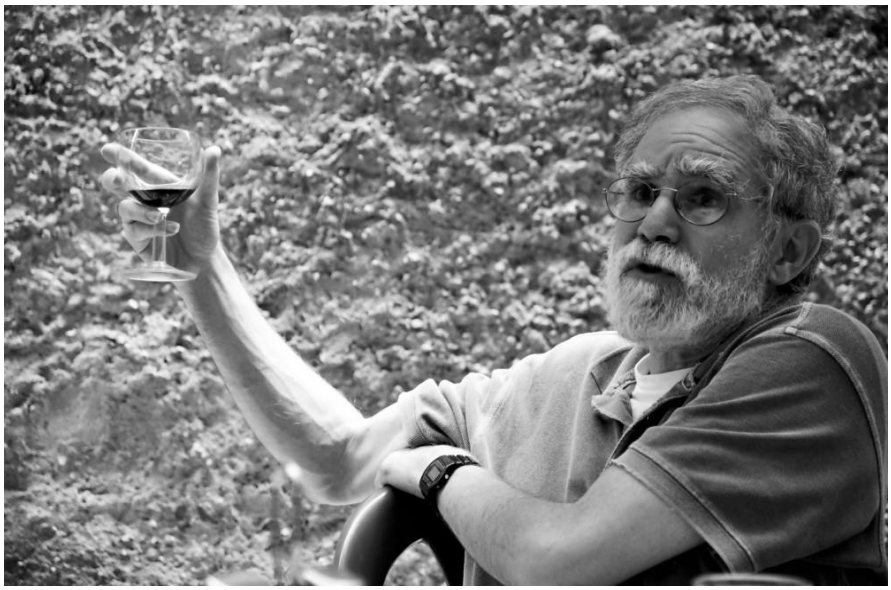
Bitter Pill

Students in quantum mechanics classes around the world are told that if they just swallow that big, nasty, quantum-mechanical pill, it will all make sense—or, well, maybe not, but at least they'll be able to do the problem sets. If you were one of those students, Goldstein, Dürr, Zanghi, and Tumulka have some shocking news for you: "You've been swindled."

Given up on determinism? You can have it back, the team says. Don't like randomness and paradoxes? Get rid of them!

The standard interpretation of quantum mechanics was arrived at in the 1920s, at a seminal meeting of the founding fathers of the theory in Copenhagen. However, Goldstein, at Rutgers University in New Jersey, believes this interpretation was built on shaky foundations made up of vague and implausible assertions. "What people are taught, the normal textbook theory, is in a very strong sense not serious, though you're not supposed to say it," he says.

According to the Copenhagen interpretation, before quantum objects are observed, they exist as *wavefunctions* that can contain a superposition of many mutually contradictory properties. It's only when an observer makes a measurement that the wavefunction collapses, and the particle settles on one of these properties. But it is this sort of fuzzy description that troubles Goldstein. "Take this idea about the collapse of the wave function on observation. It's utterly vague about what's meant by observation," he says.

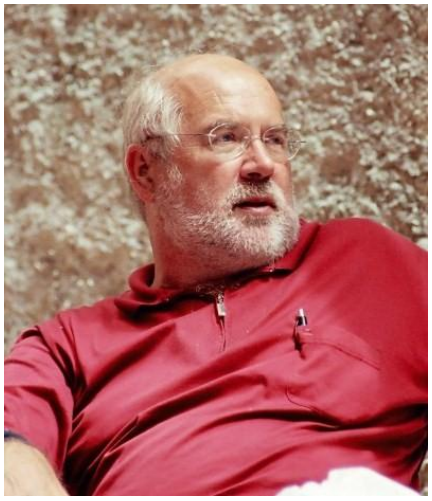


"To determinism!"
SHELDON GOLDSTEIN Rutgers University

Quantum Bullying

Students have been bullied into accepting a theory that does not makes sense, says Goldstein. "If students are bothered by this kind of question, they're given the impression it's because they're just not smart enough or sophisticated enough to understand the real depth of quantum mechanics," he says.

Indeed, the incomprehensibility of quantum theory nearly drove Detlef Dürr, now at the Ludwig-Maximilian University of Munich (LMUM) in Germany, out of the field after he completed his Ph.D. "It was clear to me that I was not a physicist since I couldn't understand quantum mechanics, which everyone else seemed to understand with ease," he says.



DETLEF DÜRR
Ludwig-Maximilian University of Munich

Dürr took shelter in the quantum-free world of classical mechanics, joining a group at Rutgers University as a postdoctoral student in 1979. There he met a "Moses-like" physicist, tall and thin with a long beard, whom he discovered was a fellow refugee from quantum mechanics. It was Sheldon "Shelly" Goldstein.

Quickly, the two developed a friendship and began collaborating on problems in classical mechanics. Although they were still needled by worries over quantum mechanics, they pursued those questions only as a sideline. Dürr still needed a permanent job, so he had to get solid results and didn't discuss his doubts about quantum mechanics with physicists other than Goldstein. "I was hiding behind my regular work and hoping that nobody understood what I was *really* doing," Dürr says.

The two physicists pursued the question in different ways. Goldstein used *stochastic mechanics*—a branch of physics that deals with random processes—to describe the probabilities that seem to govern quantum behavior. Stochastic mechanics, however, still relies on intrinsic randomness, which Dürr found unsatisfactory.

Out of the Closet

"Shelly is a more reasonable guy than I am," Dürr says. "I was the one who said let's try to derive quantum mechanics from classical physics. I was thinking like a crackpot!"

When Dürr secured a long-term position at Bielefeld University, in Germany, in 1984, he finally "came out of the closet" and openly began work on a classical foundation for quantum mechanics. Dürr received some unexpected help on his quest a year later, when a giant of a man filled the doorway of his office. This new acquaintance had just arrived as a postdoc and boldly announced to the director of the institute that quantum mechanics didn't make sense and that he was determined to reconstruct it from classical physics. The director had sent him straight to Dürr.

The "giant" was Nino Zanghì, now at the University of Genoa, in Italy. Dürr was amazed by his audacity and immediately liked him. A collaboration to derive quantum mechanics from scratch was born.

> I was touched by nature, by the sense that nature makes.
>
> *- Detlef Dürr*

Goldstein, Dürr, and Zanghi teamed up, criticizing and attacking each weak point in one another's arguments. Out of the haggling came a remarkable realization: the random element of Goldstein's stochastic mechanics could be cut out of their formulation of quantum mechanics. What they were left with filled them with astonishment.

Bohmian Rhapsody

The team had rediscovered an alternative interpretation of quantum mechanics that had originally been espoused by physicist David Bohm in 1952.

Bohmian mechanics does away with fluffy notions of wave-particle duality—instead particles really are particles that occupy a definite position in space, regardless of whether or not they have been observed. On the subatomic scale, however, their motions are guided by a *pilot wave*, which isn't a physical wave but rather a wave through a high-dimensional mathematical space. The pilot wave is responsible for the wave-like behavior seen in experiments, for example creating wave interference patterns.

Dürr had vaguely heard of Bohmian mechanics as a student—when it had been derided by other physicists. At that time, he hadn't given it serious thought. Now, he and his colleagues looked at the old theory in a new light. Seeing it fall naturally out of their mathematical manipulations gave them a profound sense of triumph—a feeling that Dürr likens to that of God creating the world. "I was touched by nature, by the sense that nature makes," Dürr says. "It's an enormous feeling."

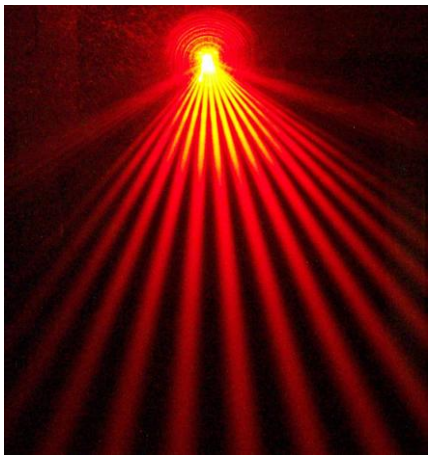
The beauty of Bohmian mechanics, says the team, is that it can predict the outcomes of quantum experiments just as well as standard quantum mechanics, but without any troubling, "mystical," counterintuitive notions.

According to Bohmian mechanics, quantum behavior only *appears* to be random because we do not have access to all the features that contribute to the dynamics of particles. The randomness of quantum mechanics is no more mysterious than the unpredictability of a tossed coin, says the team. If you know the precise nature of the toss, the motion of air currents in the room, and so on, you could completely determine whether the coin will come up heads or tails. However, since we don't know all those details, the coin toss appears unpredictable to us.

Goodbye Paradox

Subatomic particles behave in just the same way, say the researchers. The outcome of quantum experiments is perfectly determined by preceding events, and the guiding hand of the pilot waves, as long as we know all the controlling factors.

If we know all these variables, then the equations of Bohmian mechanics can tell us how particles will move, just as Newtonian physics explains the motion of the planets. "Everything can be explained easily," Dürr says. "No paradoxes, no mysticism, nothing strange."



GUIDING LIGHT
Bohm's pilot waves determine quantum paths
Credit: J. S. Coulter

NINO ZANGHI
University of Genoa

But when the trio trotted their ideas out into the world, they were met with hostility. Bohmian mechanics has never managed to win over the majority of physicists, many of whom feel that is too contrived. Goldstein puts this down to physicists' understandable reluctance to abandon the familiar.

"There's something very exciting and romantic about quantum mechanics," Goldstein says. "Suppose you've made the effort to learn all of that. You're proud of it. You can accept and have understood all sorts of deep ideas that the man on the street would have no clue about." Any physicist would be proud of such intellectual achievement and would naturally cling to it, he says.

"It's not going to be easy for you to accept under those circumstances that you've been swindled. It's hard," says Goldstein. "Scientists are people at the end of the day. It's just as hard for a scientist to be rational and unbiased as anyone."

The collaborators respond to the skepticism they meet in different ways. While Goldstein is unfailingly polite to critics, Dürr takes a different approach, as Roderich Tumulka can attest. The pair first met when Dürr came to Frankfurt to give a colloquium in 1996.

Tumulka, then a student, recalls that Dürr, with his bushy white beard, big belly and bald head looked a bit like Santa Claus. As soon as Dürr spoke, however, he quickly dispelled this jolly image. "It seemed like he was attacking everyone, but in a substantive way," says Tumulka. "He was very emphatic about it. I found it rather inspiring."

Here's a guy, Tumulka thought, I'd like to work with. Indeed, two years later, when Tumulka was ready to start on a thesis, he followed through on that resolve and contacted Dürr. Visiting him at LMUM, the young researcher eagerly shared his ideas—only to be quickly cut down. Tumulka remembers the encounter with a rueful laugh: "He analyzed my proposals and was frank with how stupid they were."

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>
> *- Shelly Goldstein on why physicists are reluctant to abandon quantum mechanics*

Tumulka left the meeting depressed. "It was not so easy for me to accept," he admits. "On the day when I left Detlef's office, there was maybe a 50-50 chance whether I'd hate Detlef or love him." But two days of thought swung the balance in favor of friendship; Tumulka decided that Dürr's criticisms were right and he asked him to be his advisor. They worked together so well that the mentorship turned into a collaboration with the whole group.

The intense criticism that initially shocked Tumulka has turned out to be essential to the collaboration. The colleagues scrutinize their work rigorously. "If I have an idea about something, the first thing I do is to write to them to find out whether it makes sense or not," Dürr says. "You can fall off the cliff, you can become a nut, you can say things that are just unreasonable. That can easily happen."

Strong Support

The collaboration gives the physicists a refuge from the hostility of other physicists. "In a field like this, if there's so much antagonism you could become discouraged, particularly if you're alone," Goldstein says. Indeed, Bohm became disheartened late in his life, troubled by worries that he had destroyed his students' careers. "Quite naturally, if everyone is against you, you could think you must be wrong," says Goldstein. "With a group of colleagues, you can support each other."

The four physicists do most of their work together now, exchanging email half a dozen times a day or more, day in, day out. The Bohmian perspective can be applied to most areas of physics, and the researchers are slowly tackling one area after another.

One of the inescapable facts about objects at the quantum scale is that particles can become entangled such that one can instantaneously affect its partner far away, without the mediation of anything in between. Einstein called this "spooky action at a distance" and rejected it since it seems to be incompatible with his theory of relativity. The most pressing problem the physicists are now working on is to resolve this incompatibility, using the Bohmian version of quantum mechanics.

The physicists' collaboration extends well beyond the professional, and they've become good friends. "It takes not just intellectual compatibility, there has to be emotional compatibility as well," Goldstein says. "Each of us has a strong appreciation of mathematics and mathematical beauty."

"I can't think of my life without these three friends," Dürr agrees. "We are, in a sense, best friends."

RODERICH TUMULKA
Rutgers University