QUANTALLY SPEAKING

Quantum mechanics, that mysterious, confusing discipline, which none of us really understands but which we know how to use … is not a theory, but rather a framework within which we believe any correct theory must fit.

Murray Gell-Mann (1981)

The quantum theoretic description of physical reality is exquisitely strange and profoundly mysterious.

David Mermin (1990)

Quantum theory is rife with conceptual problems and contradictions.

Jim Baggott (1992)

It is often stated that of all the theories proposed in this century, the silliest is quantum theory. Some say that the only thing that quantum theory has going for it, in fact, is that it is unquestionably correct.

Michio Kaku (1994)

There is, in principle, no knowable mechanism behind quantum mechanics.

Spencer Scoular (2007)

It was Max Planck who solved the blackbody problem, at a cost. The price was the quantum.

Manjit Kumar (2008)

Today he carries in a coffee from the Bean on Lankershim, gesturing he's sorry for preferring it to mine. Is this why he sits sedately as I tell him that today we cross a line? In physics the term 'classical' is flung around promiscuously. In relativity it signals absence of all quantum theory. Walking through the quantum door we cross the New Divide. He may feel we leave behind the classical. Truth is, he'll find, it tags along, as Cyco Miko sings.

What I don't tell him is that I don't know enough. Not about the physics, not about the history, not even the philosophy. Not about her. Everywhere I'm skating on thin ice. The only way I know to stay ahead of thin-ice trouble is to skate like stink.

So next I tell him relativity affects the stage where physicists play physics. QM changes physics.

Then I say that *speaking* about quantum theory runs a risk. Some physicists express strong views on the futility of speaking—using words—about QM. They believe its math is the reality and words are fluff. Who knows? They may be right. No doubt they are right about *my* speaking. But then again the idea is not for me to teach him or for him to learn QM. It's for me to sketch and him to suss the 'hood. So I give him a heads-up: No math maybe means no substance.

Just the words 'quantum mechanics' likely made him want to skip it, fearing that he will not understand it. And he's right: He won't. But no one understands it. Absolutely no one. How can this be so? Well, everybody says QM is weird. A physicist with QM is a savage with an iPad, I go on. QM says little bits of matter should do things that seem supremely silly. No one knows why it would work at all. But it is stunningly successful. It drives all those gadgets people carry round.

Einstein famously rejects it. He worries that its physics has lost contact with reality. And too, it's rife with contradictions. No surprise that no one understands it. Fortunately Frank won't need to understand it; he'll just need to know it has two heads.

The first head is the theory. But then, as Gell-Mann says, it is not really a theory. He calls it a framework but from where I sit it is a mess of math. Its formulas say how a quantum system should behave. An atom, for example. It predicts everything an atom does. Or, more precisely, it gives odds for every thing that it could do. Its calculations may be messy; its results are rarely in dispute. In all kinds of situations they're right on.

The second is interpretation: What does it *mean*? Well, that's entirely up for grabs. Maybe it means nothing. It's a heated controversy. Memo to Frank, I say: You may need to know about this. Why? Well, QM says strange things about things that are small. The Beginning that he's seeking may be small. That's not to say QM can find it for him. There are reasons to anticipate it can't. But, in the world of small, QM is what he's got.

He tells me that tomorrow he'll bone up on what it means. This, it seems he thinks, should do the job. A bit pissed, I mutter 'roos are loose in his top paddock. He doesn't know what this means either.

To make matters worse, QM has more meanings than there are physicists—it's like that one about: Two Israelis make three parties. I flash him my list of its interpretations:

Consciousness causes collapse

Consistent histories

Copenhagen

Decoherence

Hidden variables

Incomplete measurements

The instrumentalist interpretation

Many minds

Many worlds

Modal interpretations

Objective collapse

The participatory anthropomorphic principle

Quantum logical

The wave function is real

The realistic statistical interpretation

Relational QM

The stochastic interpretation

The transactional interpretation

He doesn't need to read it. A glance should show QM has physics all at sea. I tell him he should check it out; he needs to get his own sense of this mess. What I don't tell him is each item on my list reflects a slew of views.

By far the best-accepted is the *Copenhagen Interpretation*. It's named for the city. That is where, in 1924, it all begins. Heisenberg is there. He's on a scholarship. He works with Niels Bohr. Bohr has a Nobel prize. It's for his work on QM and atomic structure. Werner soaks it up. He returns to Germany. He co-authors QM math with Born and Jordan in Göttingen. Next year he's back with Bohr in Copenhagen. The four cook up a consensus about what QM means. Or so it is now said. Actually, I tell him, no two of them saw it the same way. Through a tangle of upheavals—in ideas, politics, impending war—this non-consensus shapes terrain that he may need to reconnoiter.

Heisenberg's new QM math depends upon a concept. He calls it the *Uncertainty Principle*. Well, actually, in German it's a clunky über-German compound word: *Ungenauigkeit*. As in any language, German words have shades of meanings. My *Hochdeutsch* tells me that *genau* should translate in this context as 'precise,' not 'certain'. So his word for his concept, *Un·genau·igkeit*, means un·precise·ness, or would if this was a word. Haas calls it inexactitude. My two-bits' worth would be imprecision. The Imprecision Principle doesn't sound as sexy, but it might be more descriptive. The idea is, the more precisely one can measure one thing, the less precisely one can know some other. Whatever; *Ungenauigkeit* becomes uncertainty. Such twists in translation conceal nuances in writings on QM. And they have nuances. He needs to know they're there. His task is tough enough; he needs to get the message.

The message includes Heisenberg's new principle. It is basic to the QM picture of the quantum world. He's listening, intent. Last time it didn't work but I decide to push my luck. I say let's take a closer look. It works like this: QM says attributes of, let's say, a particle are linked in pairs. One pair is its speed and its position. QM says measuring one attribute, say speed, limits how much can be known about the other, in this case position. This can be expressed in numbers. Multiply the two 'uncertainties' together; the answer's always larger than a certain number, the *Planck constant*. So when one pins down one paired attribute there's not a lot to know about the other.

This Planck constant is a tiny number. It's called $\hbar$ (aitch-bar). Physics sees it as important. I explain it to him this way: If $\hbar$ could be tweaked a little—say 20% up or down—our universe would vanish, everything from atoms up to supergalaxies all gone.

Suddenly it strikes me *my* Frank would see $\hbar$ in another way. He wouldn't see it as a little number. He'd see it as a giant clue. He'd ask me questions that I couldn't answer. Like: How did it begin? Who chose the number? And: Why measure speed? Why pick position?

What would he be getting at? Could they be *wrong* things to measure? Maybe, he thinks—or I think for him, trying hard to think the way that I think he would likely think—it is like a code. Does he, as I do, see us setting out to crack it? Does he see us searching for the message, checking for a pattern in a cipher on a page?

I'm sure he would share my worry. He'd picture Holmes, smudged with chalk dust, looking for a pattern in the crooked men. What if they were coded with a one-time pad? There would *be* no pattern. I read papers saying speed is an illusion and position isn't real. Are we seeking to make sense of things that have no sense to make?

Another image: Einstein this time, sitting in the patent office setting out to measure space and time. He measures them with rods and clocks. If he could, my Frank would second-guess him. What else could he use? Maybe he wouldn't make a lot of sense. But one thing I'm sure of: *He'd* be on the case. A wave of keenness washes through me until I look at the Frank we've got; it dissipates and I think: Not.

The consensus crew turns to a simple question: What does it *mean*? Not because they give a damn. They say this isn't even physics. But they fear it is a PR problem that could undermine their physics, about which they *do* care. So they ponder and they argue and they hammer out a compromise. Born comes up with a name: *Quantenmechanik*. They get their ducks in a row behind it. Well, more or less, I say to Frank. But that can wait.

The compromise comes to be called the Copenhagen Interpretation. It is itself the subject of interpretations. It's sobering that many of them claim they're based on Bohr. Bohr's words are almost biblical. He writes a lot and what he writes may be important. I skim over it, then skip it. Why? I can't explain to my student. Fact is *I* can't understand it.

I find a version that I like. It comes from Mermin. He says: 'Shut up and calculate.' I hand it to Frank on a scrap of paper and suggest that he could check it out. A hopeful sign: He goes to Google.

So now I have to feed him Copenhagen. Just a little; it's not easy. Learned writers see it different ways. Heisenberg's way is the first one. It goes like this: A *Wave Function* describes a system (an electron, say, an atom, or a cat); this description is complete. That is, says Werner, it says all about the system that there is to know. It gives the odds that it will do the things that it can do. It's not that for some reason we can't find out more than that. There *is*, he says, no more to find out. As a worldview this seems consummately German.

My own worldview doesn't matter. But I don't buy this one, not even Mermin's version. QM is strangely, exquisitely mysterious. There must be more.

But Copenhagen says there's not. Heisenberg and Bohr are its movers and shakers. This phrase is O'Shaughnessy; I mean it his way—kindly. After the mid-1920s, QM gains acceptance as physicists discover how it works. Bohr says it works *because* its math ignores all world views, *because* it says there's nothing real behind the math.

Certain aspects all seem to accept. For example, QM assumes that space and time exist. Everyone agrees with that. Not that it *should* assume this, mind you, but that it does. Another thing most agree on is: The Wave Function isn't real. It's a mathematical idea, nothing more. Bohr goes further; he says there can never be a theory in which any such thing *is* real. But there are nonconformists, David Bohm among them, who build theories in which something like it really does exist. Some say it runs the universe. Whatever *it* is.

But there is no broad consensus. For example, many say a particle is never *at* a place in space. It is spread like lumpy peanut butter on a universe-sized sandwich. Seems like it could be anywhere; no one knows until they look. In fact, it *isn't* anywhere until somebody finds it. This gives new meaning to her favorite expression: Check it out.

Then there is what happens when a particle is moving. SR and GR assume it has a path through space. This path is real. It is continuous. By contrast QM says a particle takes no path whatsoever. It is described by its Wave Function, which changes over time. This includes everything that *could* happen to it. Copenhagen says that nothing ever actually happens to it. If you want to know something, says Copenhagen, you must measure it. Strangely, it says you *must* use ordinary, non-quantum instruments. When you do, the Wave Function collapses and you find the particle. You discover its position and condition. They show up with a kind of jerk. As Cushing puts it, 'Central to Bohr's vision was his "quantum postulate"—the discontinuous transition of an atomic system from one stationary state to another during an interaction.' Discontinuous? To Einstein this is way beyond the pale. He's not buying the idea of a world that works in jerks.

Cruising pages, I soon find that ψ, the Greek letter psi, stands for the Wave Function. I find too that one multiplies its size by itself to get the odds of this or that. End of story: QM has nothing more to say. In especial it says nothing about *how* what happens happens. In fact Bohr and his buddies say 'How did that happen?' is a question physics doesn't ask. In other words, they say causality, aka cause and effect, has no place in physics. And I naively think that this relationship's what physics is about!

She walks in with her usual chit-chat after he has left. Then suddenly *she* wants to know what Copenhagen's all about. And what I think of it. Don't ask me why. I mean, isn't it all politics? Who cares about the technical details? Well, it turns out that she does, or that she says she does. I tell her it may take a day or two. Truth is I could tell her now but I don't need a new distraction. I've got him *doing* something for a change. He's interested. I'm on a roll or else he's putting on an act. I want him to get a feel for QM. One way would be for him to see that it's part of his life. So I dig deeper for tomorrow's lesson planning. I ask the Web: What does QM do?

It turns out there are many answers. QM shows what small things like atoms and electrons can do. But then these small things make up large things. For example, QM says: Add odd atoms to a single crystal; slice it up; add more layers; soon you have Intel Inside. There's no need to know *how* atoms do it. Knowing *what* they do is good enough. Anybody asks for more, the answer is: Shut up!

But my head won't stop asking. I can't do the math; not even close. But I can wonder why QM predicts weird things that make no sense. And with new techniques—often from QM itself—science sees these weird things happen just as QM says. Some are now ordinary, like:

Interference—particles behave like waves

Superconductivity—electric current flows forever; battery is not required

Switches—crystals control currents

Giant magneto-resistance—tiny heads track vast amounts of data

Superfluids—liquids flow with zero friction, even uphill

Lasers—solids, liquids, gases emit pure, straight beams of light

Others are more recent, like:

Teleporting—it's for real

Concealment cloaks—not Harry Potter

Quantum chemistry—makes grassoline from grass

QM is an economic engine. A host of things we take for granted depend on it—from MRI for diagnosis to the magnets of the LHC; from fridge magnets to cellphones; from electron microscopes that see cells to sensors that see mineral deposits. These are, I plan to tell him, things that QM does that are unthinkable according to the physics that was said to be complete before it came along. And it can predict things to one part in a billion. It's hard to argue with this sort of success.

All this leaves me with a quantum worry. Mermin sums it up: 'The mathematical language … refuses to talk about what actually happens, beyond giving you the odds for the various possibilities.'

Overall it's been a good day. But I don't want to kid myself. With him QM's truly good for one thing only. In the end it's guaranteed to turn him off. My problem is: Without it, can we figure out a thing that is the first that *ever* actually happens?