IT'S COMPLEMENTARY

In picturing an object at an absolutely definite position in space we cannot seem to help picturing it as fixed. In other words, we cannot think of the position of an object and of its velocity simultaneously.

David Bohm (1951)

Cosmologists, even more than laboratory physicists, must find the usual interpretive rules of quantum mechanics a bit frustrating.

John Bell (1981)

To the outside world, [scientists] present science as a series of great discoveries, as smooth upwards progress towards truth. But inside science, fierce debates and controversies rage constantly.

Jay Kennedy (2003)

Nothing is what it seems!

Slipknot (2004)

One thing's for sure: She may be educated but she can't even *spell* team. As is not uncommon, Frank is back to moping, helping nothing, rearranging books and papers with his butt. She sits with her back to him, paging through a diary on her Mac. Does she even notice? How does one spell disfunctional? Spell-check says *dys*functional.

He mostly shows up when she isn't in the office. Or vice versa, I don't know. But when she is there and he is and she talks to him she stands hipshot. She looks past him at the wall. What is that about?

So? is what I want to say aloud. Or maybe: So . . . ? in I suppose a less aggressive way. Just to say something that is nothing in particular to hack a hole in the emotive haze that hovers here today.

No one is saying much about the last few days. It's been like: Thud, thud, thud. My headache echoes the imagined sound as all my work on the three theories hits the dust. Frank is looking peevish, like he has something better he would like to do. Not. If he did he wouldn't be here. She is shoving slips of paper back and forth, receipts I imagine. She finds pleasure in receipts. Oh well, time to toggle off the markup. Maybe someday she will catch me at it and all this will end.

Late morning I kick off by telling him the pivot post of quantum theory is that it's complementary. This draws a blank look. Perhaps he thought the quantum stuff was done. I press forward to its noun, Complementarity—about as ugly as an English word can get. It's a hand-me-down from German:

komplementarität.

And what is it? Well, like I tried to say, it is the heart and soul of quantum theory. You could say it is about *Duality*. That's the idea of opposites like Yin and Yang. His disdainful look as I explain this is like: This is German? Or maybe: This is *physics*? Well, no, it's Taoist; it's philosophy. But the consensus crew adopts it, with a twist: It becomes not *a* principle but *the* most basic concept. Or so they say. For my money, I caution him, it's oversold. It's sad and hilarious how money—the mere mention of it—seems to wake him up. Like his brain is saying to him: What money? What he should be asking is: Is it real? Is it *the* most basic concept or an ad campaign?

The modern version of the principle kicked off its career about a hundred years ago courtesy of Einstein—I should have guessed. Its early permutations said that an object can behave as a particle or it can behave as a wave. It *is* both at the same time but it can't *do* both at the same time. One can check at any time to see which it is doing. But choosing *how* to check decides the answer. This may sound silly. But in a zillion tests it always works. It works for every kind and size of object, big or small, pachyderms and popsicles, protons and photons. It makes no measurable difference for big things so nobody wastes their time. For small things it makes all the difference in the world. As in, literally, now you see it, or you don't.

So, Hey! I say to him, welcome to the weird world of Complementarity. It's our world, or so we are supposed to understand. He doesn't need to say a word to let me know that he is unimpressed. He thinks I ham it up too much. He might be right, I want to capture the exhilaration that the physicists exude.

Its story starts with Huygens in the 1600s. He is a philosopher and so, as they all are in his time, he is a dilettante. He studies Saturn. He makes clocks. And he does things with light. He shows, or thinks he does, it is a wave. Like all his friends he knows a wave must wave *in* something—air, water, even sand, that kind of thing. So he must find a something for light's wave to wave in too—but what? Well, its medium, he says, must be invisible! He says it is an aether—an ancient label. The luminiferous aether, because it is the medium for light. Perhaps he thinks this is a harmless concept. If so, he's wrong. It's an idea.

Newton's next. It's 1704, a dozen generations of my ancestors ago. In his epic treatise *Opticks* he says light's a stream of particles: no waves so no need for an aether. He is the most influential thinker of the age. His view looms over scientific thought until the early 1800s when Young conducts a series of experiments that seem to show that light is like a wave. His experiments are simple. It's not that they are better than Newton's; but they are newer. Huy-

gens is ascendant; waves and aether, welcome back. Soon Newton's particles of light might get forgotten in the rush to find an answer to the question: What *is* this new and interesting aether? Mark it well, I say to him. It may be fickle fashion but it will not disappear.

In 1847, Faraday's experiments with light lead him to say it is a wave that is electric and magnetic and it doesn't need an aether. Two decades later Maxwell does the math. For physicists math has a way of ending conversations. Talk turns to chalk. All is now clear: Light *is* a wave.

Well, it *is* clear until Einstein shows that light is made of quantum particles. But this doesn't lay the waves to rest; rather it kicks off the kludgy concept behind that ugly word, Complementarity. Soon Bohr is promoting it. The more he talks it up the kludgier it gets. How come? Well, Beller says that 'the complementarity principle was a device of legitimation—it led to no new physical knowledge.'

In the washroom down the hall I show him an example. I cut a skinny slit into a piece of paper. I turn on the light pointer I bought for the lectures no one gives. It's a laser. I tape it to the counter. Lights off, it makes a red dot on the wall. I hold the paper so the light beam hits the slit. It makes a red band on the wall. Next I stick a piece of thin black thread along the middle of the slit. Now there are two slits. No doubt he expects to see two light bands on the wall. So he's surprised. There's a *bright* stripe on the wall right in the center. It's where he thinks the thread should block the light. Fainter stripes of light splay out on either side.

I try to enlighten him: The light beam is behaving like a wave. The wave that passes through one slit is interfering with the wave that passes through the other. Where they reinforce each other—for example, in the center—the light on the wall is bright. A little left or right of center, one half-beam must travel further than the other. Where the wave from one slit's going up as the other's going down and vice versa, they cancel so there is no light. The stripes are interference fringes. I can see he is impressed. But there's nothing strange about it. The light is just behaving like a wave. The same thing can be done with water waves. One might think the ball is back in Huygens' court.

But these days physicists can take a closer look. First they can turn the light source way down so that it emits one photon at a time. I ask him to guess: What will it do? Each photon that hits the wall must go through one slit or the other, right? It *can't* interfere with a photon from the other slit because there *is* no other photon. So it should just hit the wall in line with its slit. To see what happens physicists employ a fancy screen that records where each photon hits.

What they find is that the photon hits show interference fringes. It's as if each one can reinforce or cancel out itself! In fact QM seems to say that that's exactly what it does. The Wave Function for a single photon heading for the screen is in the mixed quantum state <went through left slit> and <went through right slit>. The probability of finding it at any particular location is given by the square of the Wave Function, which looks exactly like the interference pattern that's observed. But just a moment! QM also says these words, 'a single photon heading for the screen,' have no meaning. They describe the very thing that Heisenberg says can't exist. There really *is* no photon heading for the screen. There's just a source, a slit and an experimenter who sees something on a screen.

Now here's where it gets tricky. The experimenter adds a counter to detect each photon as it passes through a slit. When turned on, it clicks to show a photon passed. But now the interference pattern disappears! In its place there is what Frank expected—two bands of dots in line with the two slits. Just switch off the counter to get the interference pattern back.

It's called the double-slit experiment. Some say *the* most beautiful in physics. I show him movies on the Web. They can use electrons in place of the photons. I tell him: Check it out. They can shoot neutrons or even atoms, always with the same result. If there's no information about which slit each particle goes through, they get an interference pattern. It's what QM predicts where the <left slit> and the <right slit> versions of each particle can interfere. But the instant the observer has any way to know which slit each particle goes through, the interference pattern disappears.

Classical theory says this cannot happen. QM says exactly what is seen. It makes no sense except it happens. QM is about results.

He heads out before rush hour as usual. Am I imagining that he is thoughtful?

I too am thoughtful. I view it from *my* Frank's perspective. On one hand he'd want QM's help to find the way the universe began. He's not alone. Most everybody says it's needed. But on the other hand QM needs an observer who's outside the system. Which is a thing a universe can't get.

I know what Real Frank's problem is. It's that he's real. In a business as taxing as discovering a universe, this could really stuff him up.