How little we know about the uncertainty principle
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> Heisenberg: Are we doomed to disagree then on what happened between us at Copenhagen?
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> Bohr: But that is the whole point, Werner. You yourself have shown that uncertainty is a fundamental part of nature – that there is always imprecision in our knowledge of things.

The disturbing thing is not that these lines don't appear anywhere in Michael Frayn's play *Copenhagen* (I made them up), but that if they had, few people would have batted an eyelid. For isn't that what Heisenberg's uncertainty principle tells us: that uncertainty lies at the heart of everything?

In fact, Heisenberg never said any such thing. Some scientists today lament the snappy name that the German physicist chose for his unquestionably remarkable discovery in quantum mechanics. If he'd called it the Principle of Non-Commutation of Conjugate Operators, artists, writers and philosophers might have been less eager to seize on it as a leifmotif for the state of modern humankind.

One of the implications of Heisenberg's discovery is that in some experiments an attempt to make a measurement irrevocably alters the state of the system being measured. If you look, you change what's there. Some have concluded with delight that science has thus been hoist by its own petard—or, as David Lodge put it recently in the *Guardian*, "the discovery in quantum physics that an event is ultimately inseparable from its observation [undermines] the assumption that science is objective and impersonal."

At the root of this misconception is a contemporary erosion of the notion of metaphor. (Novelists, of all people, should understand the distinction between metaphor and reality, but here Lodge has lost it.) Frayn pulls off *Copenhagen* because he never strays beyond his metaphor. The haziness and conflicts in the recollections of Niels Bohr and Werner Heisenberg of their famous meeting in Copenhagen in 1941, when Heisenberg was working on the German atomic bomb, provides an ironic echo of the 'uncertainty' Heisenberg found in quantum mechanics. Frayn never suggests that the two are in any way causally connected.

Even so, some scientists are too sensitive to misunderstandings of the uncertainty principle to let Frayn get away lightly. This theory "is often used rather loosely in popular culture to justify all kinds of relativism about truth and values", says John Cleary of the National University of Ireland. "Even Frayn may be guilty of making such vague connections", he charges.

In the popular view, Heisenberg, who formulated his uncertainty principle in 1927, identified an inescapable fuzziness at the subatomic scale of quantum mechanics. The common belief is that in this microscopic world we can never quite bring things into focus.

But that’s not what the uncertainty principle is all about. It basically stems from the order in which one performs mathematical manipulations in the equations of quantum theory. One consequence of this technicality is that there are certain pairs of properties of a quantum system, called conjugate variables, that can never be simultaneously measured with infinite accuracy. Position and speed (or strictly speaking, momentum) are such a pair. The more accurately we measure the speed of an electron, the less accurately we can know its position, and vice versa. Heisenberg’s principle tells us how much combined uncertainty must always remain.

This is the metaphor Tom Stoppard uses in his spy play *Hapgood*, in which a character says “An electron… defeats surveillance because when you know what its doing you can’t be certain where it is, and when you know where it is you can’t be certain what it’s doing.”

Well, up to a point Lord Copper. But you can know both things pretty well. The uncertainty generally remains tiny, and becomes relevant at all only when we’re dealing with particles small enough for quantum mechanics to apply. Particle physicists have to worry about these things; to biologists, they are irrelevant.

Even more significantly, the uncertainty principle applies only to conjugate pairs of variables. You can determine non-conjugate properties of a particle as accurately as you like.

Mathematician John Casti points out that this ‘measurement problem’ in Heisenberg’s theory has become garbled into a common belief that the attempt at measurement itself causes the uncertainty. “This interpretation is just plain wrong”, says Casti.

The usual argument goes like this. If you want to look at an object, you’ve got to shine light at it—to bounce photons off it. For a subatomic particle like an electron, a photon is a hefty thing to hit it with, and the act of looking knocks the electron onto a new course. Then we’re left uncertain about what it was doing originally, before we looked. But in fact, Heisenberg’s principle tells us that it all depends on what we’re measuring.

One thing it certainly doesn’t mean is that whenever scientists draw diagrams of their experiments, they are now obliged to put themselves in the picture. Far from being some mystical, holistic truth, Oxford chemist Peter Atkins sees the uncertainty principle in a positivistic light. “ I take the view that it is a great clarifier of nature”, he says, “for it instructs us to choose: speak Japanese or speak Swahili, but don't mix them.”

All the same, the uncertainty principle is not without philosophical implications. Where does the uncertainty come from? It simply pops out of Heisenberg’s mathematical equations, and to the quantum pioneer Erwin Schrödinger that was as far as one should look: he considered the quantum world too alien to look beneath the maths. But Bohr and

Heisenberg wanted more—and here again, they disagreed. To Heisenberg, the uncertainty could not be a fundamental aspect of reality, but must just reflect the limitations of quantum theory in describing it. To Bohr, the very specific and precise kind of uncertainty Heisenberg had uncovered was a part of the way the universe was built. Casti sides with Heisenberg: "Uncertainty is a result about a mathematical description of the real world, not about the real world itself. The physical world may or may not have that kind of built-in uncertainty. We'll never know, since the kind of measurements we can actually make in the real world have nowhere near the resolution that would be needed to test Heisenberg's principle."

So on the one hand it may be ignorance of reality; on the other, reality of ignorance. Now there's a metaphor – I can feel a play coming on…

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