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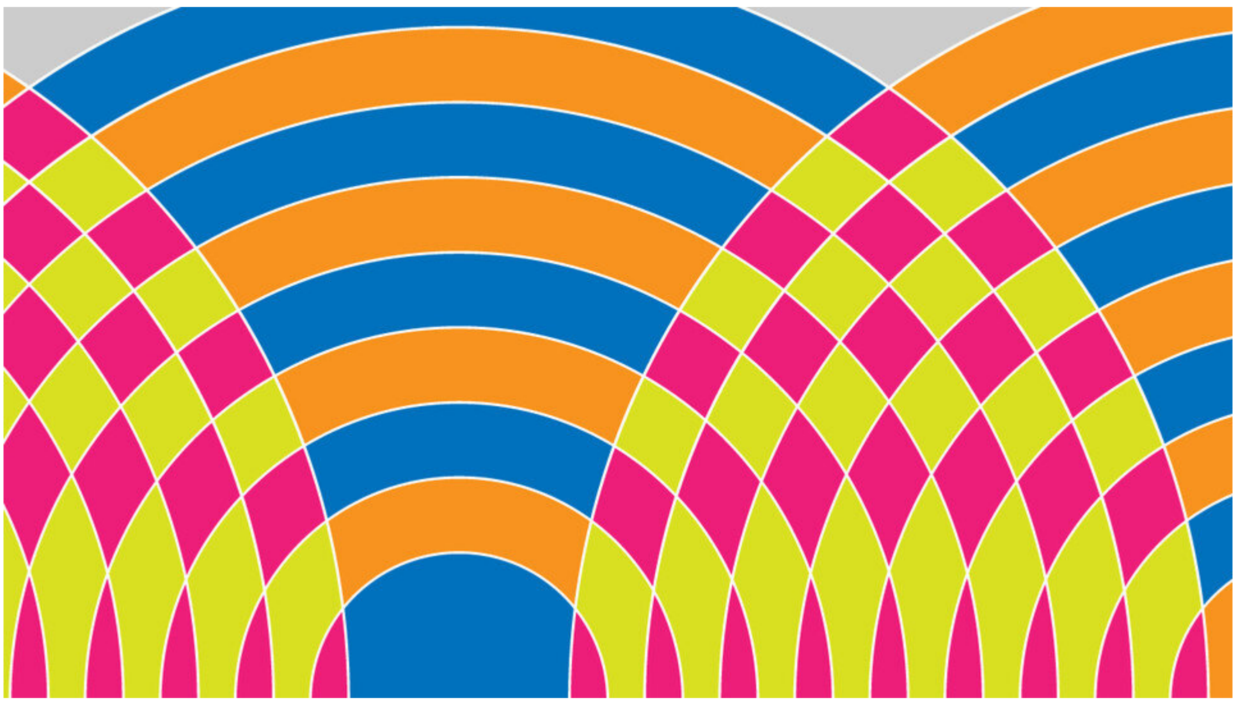
Study points to non-Newtonian force affecting particles' flight

May 30 2019, by Scott Schrage



Credit: Scott Schrage/University Communication

The quotation marks had the force of tradition—and the tradition of force—behind them.

When Nebraska's Herman Batelaan and colleagues recently submitted a research paper that makes the case for the existence of a non-Newtonian, quantum force, the journal asked that they place "force" firmly within quotes. The team understood and agreed to the request.

After all, the word has long belonged to classical Newtonian physics: equal-and-opposite reactions, electromagnetism, gravity and other laws that explain the apple-dropping, head-bonking phenomena of everyday experience.

By contrast, Batelaan and his co-authors were using the word in the context of the quantum physics that describe the infinitesimally small—where the position and velocity of subatomic particles are defined by probabilities rather than precise values, where electrons simultaneously behave like both particles and waves, and where other counterintuitive fuzziness rules the realm.

That realm got even fuzzier in 1959, when a proposed experiment suggested that the mere proximity of a classical force—rather than the force itself—could impose itself on the physical world. In the experiment, two streams of electrons sail by either side of a coil whose magnetic field is totally shielded from those electrons.

Despite the fact that neither electron stream passes through the actual magnetic field, researchers determined that the electrons' quantum probabilities would undergo measurable shifts that depend on the strength of the magnetic field. Later experiments confirmed the presence of this so-called Aharonov-Bohm effect.

But if the existence of the strange effect was indisputable, the nature of it was not. Anton Zeilinger, one of Batelaan's postdoctoral advisers, introduced a theorem suggesting that the Aharonov-Bohm effect doesn't represent or result from a force. By the time subsequent experiments from Batelaan and others confirmed that the effect did nothing to delay the arrival time of the electrons—something a force would be expected to do—Zeilinger's theorem had gained widespread support.

Years after Zeilinger proposed his theorem, though, physicists Andrei Shelankov and Michael Berry countered it by asserting that the Aharonov-Bohm effect does arise from the quantum equivalent of a force. Even if that force did not slow the electrons, Shelankov predicted that it could modify their flight trajectories by deflecting them ever-so-slightly.

"By themselves, you can understand the derivation of each theory," said Batelaan, professor of physics and astronomy at Nebraska. "They both look right, but they're in conflict with each other. So we wracked our brains to come up with a theory that gives both answers. We understood that there had to be a bigger framework.

"It begged for resolving the theoretical conflict. It begged for an experiment."

So Batelaan and his colleagues, including former doctoral advisee Maria Becker, set themselves a lofty goal: demonstrate Shelankov's prediction while also accommodating Zeilinger's theorem. Their experiment, performed at the University of Antwerp, resembled many that had preceded it: electron beams sailing toward a nanoscopic rod whose magnetic field was shielded from the particles. When the rod's magnetization was zero, the wave-like patterns that electrons formed after bouncing off it—patterns akin to overlapping ripples in water—were symmetric.

Yet when the team ramped up the magnetization, those diffraction patterns became asymmetric—indirect evidence of a non-Newtonian force nudging the electrons left or right. And as the team expected, reversing the direction of the magnetization also flipped the direction of the asymmetry, further supporting the idea of a quantum phenomenon that can affect matter in ways similar to classical Newtonian forces.

As for Zeilinger's theorem? According to the team's analysis, the theoretical assumptions that he made don't apply to the sideway motion implied by the study. Given that, Batelaan said, the study doesn't invalidate Zeilinger. Instead, the team showed mathematically that its Shelankov-predicted results and Zeilinger's theorem are two special cases of one overarching theorem.

Batelaan roughly compared the situation to one in which a ball begins rolling along a flat platform. Slowly raising and lowering that platform can change the ball's destination on one plane even as its velocity and arrival time remain the same. Looking down on the platform, an observer could miss that any shift had occurred; it might become apparent only after changing perspectives.

The issue of perspective also informs the interpretation of the study, Batelaan said. Classical forces operate locally, affecting only the matter adjacent to those forces. But quantum mechanics—notably quantum entanglement, whereby changes in one particle simultaneously manifest in another entangled particle that could theoretically reside light-years away—isn't bound by distance.

Batelaan said the team's results could be interpreted as evidence of a similarly non-local force.

"Here, we have a situation that is non-local but unlike quantum entanglement," Batelaan said. "It is a one-particle phenomenon, not a two-particle phenomenon. So can this idea of things happening without a force be applied in a different context? That's very rare. It's very, very special. I think that what we're on to here is indeed another example of it.

"I feel that this underlines the idea that nature might be non-local. This is a big question. Do the things I do here affect things somewhere else, without a clear intermediary?"

The fact that Batelaan has found evidence for it doesn't mean that he has to like it, though.

"I find it disgusting," Batelaan said, laughing. "I live in the classical world. Everything that I see around me I see happening because of forces. If there are things happening without forces, why can't I use them? Why aren't there more examples of this?

"As a physical principle, it must be everywhere. But we're (possibly) just too blind to see it."

The researchers reported their findings in the journal *Nature Communications*.

More information: Maria Becker et al. Asymmetry and non-dispersivity in the Aharonov-Bohm effect, *Nature Communications* (2019). DOI: 10.1038/s41467-019-09609-9

Provided by University of Nebraska-Lincoln

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