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Can three pigeons be in two pigeonholes with no two pigeons in the same hole?

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Research published this month in the *Proceedings of the National Academy of Sciences* (*PNAS*) introduced a new quantum phenomenon which the authors called the "quantum pigeonhole principle." Prior to this breakthrough, the pigeonhole principle was a basic tenet of conventional wisdom. It states that if you put three pigeons in two pigeonholes then at least two of the pigeons must end up in the same hole. It is an obvious yet fundamental principle of nature as it captures the very essence of counting. The research, conducted by members of Chapman University's Institute for Quantum Studies (IQS), violates this principle. The study demonstrates how to put an arbitrarily large number of particles in two boxes without any two particles ending up in the same box.

"This discovery points to a very interesting structure of quantum mechanics that was hitherto unnoticed," said Yakir Aharonov, Ph.D., and co-director of Chapman's IQS. "This now requires us to revisit some of the most basic notions of nature."

The paper, called Quantum violation of the pigeonhole principle and the nature of quantum correlations, discusses several possible experiments which explore implications for the nature of interactions between particles. The paper also introduces a host of additional new findings that the researchers discovered concerning related quantum effects. The paper also calls into question some of the most fundamental notions including that of separability and correlations.

"It is still very early to say what the full implications of this research are," said Jeff Tollasken, Ph.D., co-author of the PNAS paper and co-director of IQS. "But we feel one should expect them to be major because we are dealing with such fundamental concepts."

For example: the laws governing the quantum world suggest that things can be in many different places at the same time. So a single particle can be in both boxes at the same time—but only when you're not "looking." Once you look, and observe the particle, it will be forced to be in either one box or the other.

"But if your only tool is a hammer, then you tend to treat everything as if it were a nail," says Tollaksen. "The problem was that the 'hammer-type' measurements usually are not the most useful in figuring out how the quantum world links the future with the present in subtle and significant ways."

Aharonov and his team have worked for two decades on new types of gentle "weak measurements," which can see these linkages—"akin to tapping something softly with your finger rather than smashing it with that hammer, which forces each pigeon to be in a single box," Tollaksen says.

All this weirdness has revolutionary implications for our understanding of the most exotic aspect of nature: non-locality—the theory that particles separated by huge distances, even at opposite ends of the universe, are connected and can affect each other's behavior."Non-locality is regarded as the most profound discovery of science and is the resource for the future of technology." says Tollaksen.Experiments have already been performed confirming some of the predictions made in the PNAS paper. The experimental results were published in December in the journal *Physical Review A* by Dr. Tollaksen and collaborator Prof. Yuji Hasegawa at the Vienna University of Technology.

More information: Yakir Aharonov et al. Quantum violation of the pigeonhole principle and the nature of quantum correlations, *Proceedings of the National Academy of Sciences* (2016). DOI: 10.1073/pnas.1522411112

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