NEWS

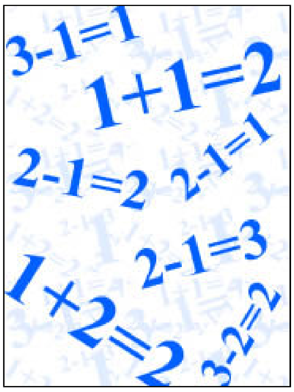
Published online: 27 September 2007; | doi:10.1038/news070924-10

This quantum stuff just doesn't add up

Mathematical quirk of light shines a path to quantum cryptography.

Katharine Sanderson

When does taking one thing away give you more than what you started with? When quantum mechanics gets involved.



With photons, 1+2 doesn't equal 2+1.

Researchers have shown that removing a photon from a laser beam can lead to it containing more photons than it had before[1]. This result, along with a few other mathematical tricks, is the first practical demonstration of one of the basic principles of quantum physics — the quantum non-commutative effect — and it is leading the way towards controlling light at the quantum level, and to quantum cryptography.

The commutative law states that when you add one object to a group, and then remove an object from that same group, the final number of objects will be the same as what you started with. That works for apples, oranges and other everyday objects. But when applied to photons, the fundamental quantum particles of light, this law doesn't hold.

To describe a property such as the momentum or position of a photon, researchers use basic mathematical operations. The most basic of these are addition and subtraction.

Researchers have shown theoretically that in quantum physics, performing these quantum operations in different orders will lead to different answers. The operations do not commute — adding and subtracting photons will give very different results depending on the order in which they are done.

It's so weird

The Heisenberg uncertainty principle provides a glimpse of this non-commutative quantum strangeness. The principle says that you can't know with certainty both the exact position and the momentum of a particle, because to measure such things you have to nudge the particle, thereby changing its properties. The mathematical expression of this principle has written into it that measuring position and momentum in different orders produces different results.

"You are working at the quantum level," explains Marco Bellini

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from the National Institute of Applied Optics in Florence, Italy. "If you did it with ping-pong balls it wouldn't work this way," he says.

Bellini and his colleagues have now shown these odd mathematical quirks experimentally. They shone a laser beam through a spinning glass plate, which adds an element of chaos to the ordered, directional laser light to make it behave like ordinary sunlight. The exact number of photons in the beam isn't known, but the mean number of photons in the light can be determined.

Watch it happen

Bellini then used a quantum-state detector to measure the mean number of photons in that beam, and then tinkered with the light. Using techniques that have been demonstrated previously, he first added then subtracted a photon from the beam before measuring the final mean number of photons. He then did the reverse: subtracting then adding a photon.

The mean number of photons in the resulting beam differed in each case. In fact, under some conditions, subtracting a photon actually changed the quantum state of the beam to the extent that the mean number of photons went up.

"It's the most direct demonstration of lack of commutativity that I am aware of," says Robert Boyd, from the Institute of Optics, University of Rochester, New York.

And it's useful

The technique could in principle be used to 'engineer' light in any desired quantum state. "You can start with normal light, and by adding or subtracting photons you can generate any sort of light you want," says Bellini. This would be incredibly useful for encrypting information through quantum means.

"This allows you to produce different quantum states at will," agrees Boyd.

"This experiment is beautiful," he adds. "Maybe it is even of practical importance."

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References

1. Parigi, V. , Zavatta, A. , Kim, M. & Bellini, M. *Science* **317**, 1890-1893 (2007).

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ISSN: 1744-7933