Complementarity probably survives challenge.

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In their *Nature* article of Sept. 3rd, S. Dürr *et. al.*[1] report the results of an experiment involving the recombination of two quantum atomic beams. The **interference** pattern disappears when they tag the two atomic wave functions traveling along different paths even when done by means so gentle that the quantum phase should not be substantially perturbed. They suggest that this indicates that quantum mechanical duality is a deeper phenomenon that can be explained by the usual "measurement-disturbs-the-wave-function" reasoning. However, interpreting their own mathematical analysis suggests that basically the interference is still there, only obscured, so no modification of conventional duality is required.

quantum mechanics
Heisenberg Uncertainty principle
complementarity quantum

The authors split a beam of rubidium atoms into two quantum sub-beams by diffracting the beam off of a sort of diffraction grating, formed by a standing wave of properly tuned light. After allowing the sub-beams to separate by a known distance, a second optical grating is used to force parts of each of the two sub-beams recombine in the far field. When the atoms of the atomic beam are in a single defined quantum state, the apparatus produces an atomic interference pattern in the far field due to the wave nature of the atomic quantum mechanical wave function, as predicted by quantum mechanics.

However, the interference pattern disappears when the authors use microwaves to pump the atomic quantum state between two sub-ground-states (which the authors denote 2>

and 3>), such that they are able to insure after the second diffraction that one sub-beam ends up entirely in state 2> while the other ends up entirely in state 3>. This pumping serves to "tag" the beams, since even after the sub-beams recombine one can know if a given atom came from the left or right sub-beam by measuring whether the atom is in state 2> or state 3>.

The usual description of wave/particle duality explains the disappearance of interference by arguing that localizing the wave function along one path or the other disturbs the momentum to such a point that the recombination is no longer coherent. Here, the authors convincingly argue that their tagging scheme cannot impart sufficient momentum to destroy the coherence. They therefore claim duality is deeper than simple randomizing of momentum. Note the interference pattern vanishes, even when one uses a detector that can't distinguish between 2> and 3>. The very possibility that one *could have* determined a given atoms path, even if one doesn't, seems to preclude the atom acting as a wave, instead forcing it to act more "particle-like."

However as their own mathematical analysis indicates and ordinary quantum mechanics requires, no interference is expected when combining beams of different, orthogonal quantum states. This is seen in ordinary light: combining beams produced by a reflective beam splitter produces interference; combining orthogonally polarized beams from a polarizing splitter does not. Indeed, this in not even a quantum effect, even orthogonal modes of ordinary mechanical waves will not produce an interference pattern.

Yet in each case the interference information still exists and can be made visible by the proper apparatus. For the authors' experiment, the atomic state after combining the beams is a quantum admixture of the two sub-ground-states in equal proportion, but with a phase difference between the states that varies as function of lateral distance in the far field, which I'll call x. That is, the quantum state is: $2> + 3>e^{i\theta}$, where the phase difference θ varies linearly with x. (Note that if the beams were in the same state, i.e. if 2> = 3> then the interference would appear directly as a $\sin^2$ variation of probability with x.) When 2> and 3> are orthogonal, the interference disappears, but the information is still inherent in θ, and can be extracted. For example, further microwave pumping should force the admixture from 2> to 3> or from 3> to 2> depending on the phase θ. Properly done, such pumping would result in complementary interference patterns, one of atoms in state 2> and the other or atoms in state 3>.

If so, their experiment (while still extremely valuable in its own right) does not challenge the conventional explanation of wave/particle duality.

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1. Dürr, S., Nonn, T., and Rempe, G., *Nature* **395**, 33-37 (1998)

2. Kunze, S. *et al.*, *Jour. of Modern Optics* **44**, 1863-1881 (1997)