Comment on "State-Independent Experimental Test of Quantum Contextuality in an Indivisible System"

In this Comment we argue that the experiment described in the recent Letter [1] does not allow one to make conclusions about contextuality. Our main criticism is that the measurement of the observables as well as the preparation of the state manifestly depend on the chosen context. Contrary to that, contextuality is about the behavior of the *same* measurement device in different experimental contexts (cf., e.g., Refs. [2–4]).

The authors aim to experimentally demonstrate that the noncontextuality assumption is violated by quantum systems. Specifically, they report a violation of the noncontextuality inequality recently introduced by Yu and Oh [5], which is of the form

$$\sum_k \langle A_k \rangle - \frac{1}{4} \sum_{(k,\ell)\in E} \langle A_k A_\ell \rangle \leq 8. \qquad (1)$$

The notation $\langle A_k A_\ell \rangle$ is an abbreviation denoting the expectation value of the product of the outcomes of the observables A_k and A_ℓ. This inequality holds for any noncontextual model, i.e., any model having preassigned values for each observable A_k, irrespective of the measurement context (the different pairs $A_k A_\ell$). Therefore, the experimenter must convincingly argue that the assignment of the observables is independent of the context. This is a central point in any experimental test of contextuality. For the argument leading to Eq. (1), it is crucial that (i) the same symbol A_k always corresponds to the same measurement and (ii) the expectation value is evaluated always for the same state of the system.

In Table I, we list the different measurement procedures that have been used in the experiment, as provided by the Supplementary Material of the Letter. Clearly, except for A_{z_1} and $A_{y_3^-}$, none of the observables is measured context independently. In particular, the observables A_{h_α} ($\alpha = 0$, 1, 2, 3) are measured in each context differently, violating condition (i). In addition, the input states are chosen differently for different contexts—an approach that has not been investigated before and directly violates condition (ii).

Since no experimental data or discussion concerning these issues is provided in the Letter, the only means to conclude that those different procedures actually correspond to the same physical observable is to invoke previous knowledge about the functioning of the optical devices. However, since the setup is operated on a single photon level, this actually requires one to employ their quantum mechanical description. But then the experiment can merely be used to verify the predictions of quantum mechanics *within* the framework of quantum mechanics, rather than to provide a proof of contextual behavior.

TABLE I. Different realizations of the 13 observables in the different contexts. In each row k, the entries correspond to the different experimental realizations of the observable A_k depending on the context, i.e., for column ℓ in the context $\langle A_k A_\ell \rangle$, for $\ell = k$ in the single observable context $\langle A_k \rangle$. In the entries, the number corresponds to the setting of half wave plate (HWP5) (1: 0°, 2: 25.5°, 3: 45°, 4: −22.5°, 5: 67.5°) and the lower case letter to the setting of HWP6 (a: 0°, b: 22.5°, c: 17.63°, d: −17.63°). Where only the number occurs, the setting of HWP6 does not influence the observable, since the observable was measured using Detector 1; if Detector 3 was used, a prime is added. An X denotes a change of the input state prior to measurement by swapping $|0\rangle$ and $|2\rangle$, while Y denotes a swap of $|1\rangle$ and $|2\rangle$. For $\langle A_{z_2} \rangle$, $\langle A_{z_3} \rangle$, and $\langle A_{y_3^+} \rangle$ it is not clear from the material which setting was used in the experiment.

	z_1	z_2	z_3	y_1^-	y_2^-	y_3^-	y_1^+	y_2^+	y_3^+	h_1	h_2	h_3	h_0
z_1	1	1	1	1			1						
z_2	1a	?	1a		3			3					
z_3	1a'	1a'	?			2a'			2a'				
y_1^-	1b'			1b'			1b'			X2			X2
y_2^-		3b'			3b'			3b'			Y2		Y2
y_3^-			2			2			2			2	2
y_1^+	1b			1b			1b				X5	X4	
y_2^+		3b			3b			3b		Y4		Y5	
y_3^+			2a			2a			?	4	5		
h_1				X2d				Y4c	4c	4c			
h_2					Y2d		X5c		5c		5c		
h_3						2d	X4c	Y5c				2d	
h_0				X2c	Y2c	2c							2c

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