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Violation of a Bell-like inequality by a combination of Rayleigh scattering with a Mach-Zehnder interferometry

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In 1964 J. S. Bell published his famous paper regarding the just as well famous Einstein-Podolsky-Rosen (EPR) paradox – a paradox that had been discussed since 1935 until Bell's paper purely on a philo¬sophical level [1]. EPR is concerned with the question if Quantum Mechanics (QM) can be considered to be a complete theory, or if we have to search for any hidden parameters to complete it [2, 3]. In his paper Bell derived an inequality that must hold for any theory of local realism, independent of whether there exist such hidden parameters or not. 5 years later, in 1969, J. Clauser, M. Horne, A. Shimony, and R. Holt published an alternative inequality – the so-called CHSH-inequality. Since then this inequality has become a much-cited relation [4]. A first experiment to demonstrate its violation in QM was put into practice in 1982 by A. Aspect and co-workers. They used polarization entangled photons to create a 4-dim. event space [5]. Several other quantum mechanical experiments have been developed in the meantime. They are of growing importance not only for questions regarding the foundations of QM but also in quantum information theory (e.g., quantum cryptography and quantum computing) and in quantum optics. Today, the violation of the CHSH-inequality in QM is accepted among most of the physicists as an experimental fact that expresses the non-local character of this theory. Moreover, it is assumed that it is exactly this non-local character that makes QM essentially differ from our classical lines of thought. The latter applies to experiments with classical particles, and, most important for this talk, to classical optics experiments.

In general, correlation measurements can be applied in a similar manner as known from scattering experiments. I.e., the deviation from an initial correlation or a combination of initial correlations can be used to gain information about the disturbance that causes the measured deviation. The CHSH-inequality - especially if it is used with parameters resulting in a maximum violation - provides us with such an initial combination of correlations. But again, it is assumed that a corresponding experimental setup can be put into practice only in QM. However, there is still an ongoing discussion regarding the possibility to perform equivalent experiments also with a classical experimental setup. In 2010 Borges et al. performed a classical optics experiment based on non-separable spin-orbit modes of a laser beam, for example, that results in a maximum violation of a Bell-like (or CHSH-like) inequality if formulated in terms of intensities [6].

In this talk I propose an alternative classical optics experiment. In the first part I'm going to discuss the CHSH-inequality and its maximum violation with conventional quantum mechanical experiments by employing an abstract state concept in a 4-dim. but classical event space. A statistical operator that contains "negative quasi-probabilities" as well as a T-Matrix can be related to these experiments. It is shown that these negative probabilities expresses the redistribution of probabilities related to the events of the considered 4-dim. event space. The importance and usage of the T-matrix is equivalent to what is known from classical scattering theory. A necessary condition for the violation of the CHSH-inequality is derived and discussed afterwards.

In the second part of this talk I want to propose the classical optics experiment that will also be able to violate a Bell-like inequality with correlations formulated in terms of intensities. For this we have to discuss an appropriate modification of the 4-dim. event space presented in the first part of this talk. It is finally shown that a combination of conventional Rayleigh scattering with a Mach-Zehnder setup would be able to accomplish this modification in a pure classical way. Thus it is demonstrated that it is questionable to relate the violation of Bell-like inequalities exclusively to the realm of QM without specifying the considered experimental configuration. But this position can be frequently found in the literature. On the other hand, classical correlation experiments such as proposed in this talk may open new ways to study and to use the violation of Bell-like inequalities in modern optics.

References:

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