Experimental Studies of Measurement Uncertainty Relations studied in Neutron Optics

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Abstract

Heisenbergs uncertainty principle [1] is without any doubt one of the corner stones of modern quantum physics. However, the present perception of quantum mechanics has deviated from Heisenbergs empiristic assumptions, reflected in his famous gamma-ray microscope where a measurement process is the source of uncertainty, resulting in a version of the uncertainty relation expressed as a product of widths of probability distributions, i.e., standard deviations (independent of any measurement). These types of uncertainty relations set limits on how sharp the values of two observables can be determined if measured separately, but provide no information of the error when measuring one observable and the thereby induced disturbance on another subsequently (or simultaneously) measured observable. However, a naive product-type error-disturbance uncertainty relation (EDUR) is not valid in general. In 2003, Ozawa thus proposed an improved EDUR, based on rigorous and general theoretical treatments of quantum measurements which is usually refereed to as an *operator-based* approach [2]. In my talk, I will give an overview of our neutron optical approaches for investigation of EDUR via successive measurements of incompatible neutron spin observables [3, 4, 5].

Another more recent experiment tests so called *operational* definitions of error and disturbance developed by Busch and his co-workers. In this theoretical framework error and disturbance are evaluated from the difference between output probability distributions of the successive measurement and reference (ideal) measurements. Despite the ongoing controversy of the two competing approaches, in the case of projectively measured qubit observables, such as neutron spin components, both approaches lead to the *same* outcomes [6].

In our most recent experiment information-theoretic, or entropic, definitions of error (in this theoretical framework referred to as *noise*) and disturbance are studied. Here, noise and disturbance are defined via correlations between the input states and measurement outcomes. We successfully carried out an experimental test of a newly derived, *tight* noise-disturbance uncertainty relation for general qubit measurements [7]. For certain non-commuting spin observables, the tight relation is saturated with projective measurements. However, there are also cases in which the relation is only tight for general quantum measurements, i.e., *positive-operator valued measures (POVMs)*, as predicted theoretically.

Keywords: Neutron, Spin, Polarimetry, Uncertainty Relations,

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