# Complementarity and Uncertainty in Mach-Zehnder Interferometry and beyond

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## Abstract

A coherent account of the connections and contrasts between the principles of complementarity and uncertainty is developed starting from a survey of the various formalizations of these principles. The conceptual analysis is illustrated by means of a set of experimental schemes based on Mach-Zehnder interferometry. In particular, path detection via entanglement with a probe system and (quantitative) quantum erasure are exhibited to constitute instances of joint unsharp measurements of complementary pairs of physical quantities, path and interference observables. The analysis uses the representation of observables as positive-operator-valued measures (POVMs). The reconciliation of complementary experimental options in the sense of simultaneous unsharp preparations and measurements is expressed in terms of uncertainty relations of different kinds. The feature of complementarity, manifest in the present examples in the mutual exclusivity of path detection and interference observation, is recovered as a limit case from the appropriate uncertainty relation. It is noted that the complementarity and uncertainty principles are neither completely logically independent nor logical consequences of one another. Since entanglement is an instance of the uncertainty of quantum properties (of compound systems), it is moot to play out uncertainty and entanglement against each other as possible mechanisms enforcing complementarity.

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