

Multiparameter quantum phase estimation for tracking of chemical processes

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Abstract

We report of a novel approach for tracking the optical activity of a solution of sucrose undergoing acid hydrolysis using a quantum multiparameter phase estimation protocol. The multiparameter estimation grants robustness against setup instabilities, providing the ideal platform for chemical samples.

Quantum metrology enables to perform measurements with enhanced sensitivity with respect to classical ones [1, 2]. In particular phase estimation has been extensively investigated [3, 4] and it has been shown that the sensitivity can be drastically improved in multiparameter scenarios in the presence of correlations [5, 6]. When considering a dynamical approach, the time scale which can be explored are limited to sub-second time scales due to the requirements of the measurement techniques. Processes occurring at these time scale are of interest in chemical and biological frameworks as many chemical reactions, and more specifically those which can be monitored by a chirality alteration, are characterized by evolutions compatible with that temporal resolution.

Here we report of an experiment on dynamical multiparameter estimation of the optical activity in the acid hydrolysis of sucrose [7, 8]. Hydrochloric acid (HCl) in fact catalyzes sucrose hydrolysis, obtaining a solution of glucose and fructose. While sucrose and glucose are dexorotatory, fructose is levorotatory and its optical power is greater than that of glucose. Hence, a change in the chirality of the solution from dexorotatory before the reaction to an overall levorotatory behaviour is expected at completion.

We track the rotatory activity using the multiparameter strategy proposed in [9]: a photon pair is generated via Type I parametric down conversion (SPDC). The two photons with orthogonal polarizations are combined on a polarising beam splitter so that a N00N state in the circular polarisation with N=2 is obtained through Hong-Ou-Mandel interference. The photons are then sent on the chiral sample which imparts a phase ϕ on the R polarisation, giving:

$$|\psi\rangle = \cos\phi(a_H^\dagger a_V^\dagger|0\rangle) - \sin\phi\left(\frac{(a_H^\dagger)^2 - (a_V^\dagger)^2}{2}|0\rangle\right) \quad (1)$$

The outgoing photons are hence projected into different polarisation to perform the phase estimation. In a realistic case, the measured probabilities will also depend on the visibility of the modulations of Eq. (1), which, if not correctly accounted for, would provide a bias to the phase estimation. In a dynamic scenario, where the visibility can change in time due to instabilities both of the sample and of the setup itself, monitoring the visibility thus becomes of paramount importance for reliably tracking the phase evolution of the sample.

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