Comment on "Neutron Interferometric Observation of Noncyclic Phase"

In Ref. [1], Wagh *et al.* report an experiment aimed at measuring the noncyclic phase for a spin-$1/2$ system using neutron interferometry. I wish to point out that, contrary to the impression one gets from the paper, the most important part of the physics of the noncyclic phase, namely the different sign of the phase shift for states in the upper and the lower hemispheres [2], is not verified in this experiment. The reason lies in the fact that this experiment measures, for whatever reason, not the noncyclic phase itself, but a quantity derived from it, namely the difference of the phase shift acquired by a given state and the linear phase shift acquired by the state $\theta_R = 180°$ or $\theta_R = 0°$, lying in the other hemisphere. For example, consider the curves corresponding to the states $\theta = 70.5°$ and $\theta = 109.5°$ in Fig. 2 of Ref. [1]. For the sake of this argument, let us ignore the small wiggle in the curves and consider them as straight lines. What needs to be shown by measurement is that the linear part of the noncyclic phase for states in the upper hemisphere is $a = \phi/2$ and that for the lower hemisphere is $b = -\phi/2$, where ϕ is the precession angle. Instead of measuring a and b, the experiment shows by measurement that $(a - b) = \phi$ and $(b - a) = -\phi$. The two curves, therefore, do not represent independent quantities and none of the two implies what needs to be shown. It is also noteworthy that the phase shifts plotted in Fig. 2 equal $\pm 2\pi$ for 2π rotations on the sphere and in this sense contain information equivalent to that in a polarimetric experiment. The quantities $(a - b)$ and $(b - a)$ in fact represent the angles of rotation of the states on the sphere. In measuring these differences, therefore, one has sacrificed the true advantage of an interference experiment in the context of spinor phases.

The curve for $\theta = 90°$ in Fig. 2 also does not represent measured quantities. The reason is, the points corresponding to $\theta = 90°$ and precession angles $\pm 180°$ are phase singularities [3], where the phase shift becomes undefined and one is not justified in making a definite choice for the sign of the π phase jumps as has been done. The choice of sign in Fig. 2, which corresponds to choosing $\theta = 90° + \epsilon$, ϵ being a small positive quantity, is arbitrary and does not follow from measured data.

It may be recalled, it was first pointed out in Ref. [2] that the well-known neutron interferometer experiments [4,5] demonstrating the sign change of the wave function of odd half-integer spin particles under 2π rotations, done with unpolarized neutrons, do not constitute measurement of the phase shift associated with a given spin state and that such a measurement would require an experiment with polarized neutrons. It was shown [2] that the continuously monitored phase shift of a spin state rotating about the polar axis, as given by the Pancharatnam criterion, with the initial state taken as the reference state (the noncyclic phase), has the opposite sign for states lying in the upper and the lower hemisphere and has a discontinuous jump equal to $\pm\pi$ for a state lying on the equator. This was verified experimentally in optical interference experiments using the polarization states of light as a two-state system which is isomorphic to the spin-$1/2$ system [2,6]. The phase jumps in SU(2) evolution occurring at points in the parameter space where the two interfering states become orthogonal, had earlier been predicted [7,8] and explained in terms of jumps in the geometric part of the phase. The origin of such phase discontinuities in the existence of Dirac singularities in the parameter space of the SU(2) transformation was demonstrated, theoretically and experimentally, for the case of two-state system of light polarization [3,9] and the occurrence of similar effects in neutron interference was predicted [2,3,6,10].

To conclude, the measurement of the noncyclic phase of an evolving spinor state along with its sign and a demonstration of the associated singularity in the case of quantum systems, e.g., a spin-$1/2$ system, as suggested by the results of the optical polarization experiments, remains an open problem.

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