Comment on "Observation of Berry's Topological Phase by Use of an Optical Fiber"

In a recent Letter, Tomita and Chiao[1] reported the first experimental verification of Berry's topological phase for the photon.[2,3] They used a helically wound optical fiber as a waveguide along which the direction of light propagation (**k** vector) is slowly changed. They showed that the angle of rotation of linearly polarized light in the fiber, which is a direct measure of Berry's phase, is determined solely by the solid angle of the path in **k** space.

We would like to point out that if we use a modified **k** space, Berry's phase can be seen in discrete optical systems[4] which contain no waveguides. As a simple, nontrivial example let us consider a three-mirror periscope shown in Fig. 1. The incident light beam propagated along the y axis ($\mathbf{k}_0=\hat{\mathbf{y}}$) is bent by three perfect mirrors, M_1, M_2, and M_3, successively as follows:

$$\mathbf{k}_1=-\cos\theta\hat{\mathbf{x}}-\sin\theta\hat{\mathbf{y}},\quad \mathbf{k}_2=\hat{\mathbf{z}},\quad \mathbf{k}_3=-\hat{\mathbf{y}}\ (=-\mathbf{k}_0), \tag{1}$$

where $\hat{\mathbf{x}}$, $\hat{\mathbf{y}}$, and $\hat{\mathbf{z}}$ are unit vectors for Cartesian axes. Here we introduce modified **k** vectors as

$$\tilde{\mathbf{k}}_i=(-1)^i\mathbf{k}_i,\quad (i=0,1,\ldots). \tag{2}$$

If we measure the helicity of the photon with respect to the modified **k** vectors, it is conserved under perfect reflections, i.e., reflections by mirrors with infinite conductivity.

With the aid of classical electrodynamics we see that the overall rotation angle of linearly polarized light is given by

$$\Theta=(\pi/2-\theta)+\pi. \tag{3}$$

Especially in the case of $\theta=0$, it is straightforward to see the 270° rotation. On the other hand, the solid angle spanned by $\tilde{\mathbf{k}}_0$ ($=\tilde{\mathbf{k}}_3$), $\tilde{\mathbf{k}}_1$, and $\tilde{\mathbf{k}}_2$ in the modified momentum space is

$$\Omega(\tilde{\mathbf{k}}_0,\tilde{\mathbf{k}}_1,\tilde{\mathbf{k}}_2)=\pi/2-\theta, \tag{4}$$

and coincides with Θ aside from the additional term π due to phase shifts by odd number of reflections. More generally, the relation

$$\Theta=\Omega(\tilde{\mathbf{k}}_i)+N\pi \tag{5}$$

holds for N-mirror systems.

In contrast to the adiabatic change in **k** vector in helically wound optical fibers, a sudden change in **k** takes place upon reflection at the surface of mirrors. However,

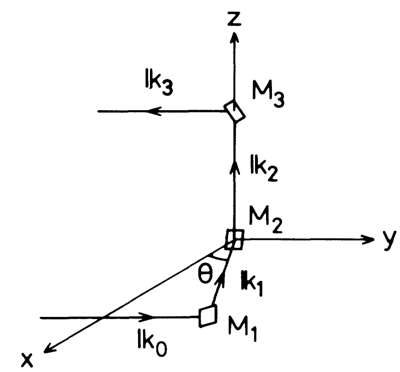

FIG. 1. Configuration of mirrors.

the change in polarization is equivalent to that which is obtained when the initial $\tilde{\mathbf{k}}$ vector is slowly (adiabatically) changed in the plane of incidence to the final $\tilde{\mathbf{k}}$ vector. So we can connect the discrete points $\tilde{\mathbf{k}}_i$ ($i=0, 1,\ldots,N$) on the $\tilde{\mathbf{k}}$ sphere by the geodesic lines in order to calculate $\Omega(\tilde{\mathbf{k}}_i)$.

For real mirrors with finite conductivity, the conservation of helicity is imperfect and the polarization of reflected light becomes elliptic. To see the rotation of topological origin clearly, we may have to choose special configurations in which birefringence in each reflection cancels out or we may have to to use infrared light for higher conductivity.

Practically, the polarization of this type has been used in a laser gyro[5] in place of intracavity biasing elements such as quartz crystals.

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[1]A. Tomita and R. Y. Chiao, Phys. Rev. Lett. **57**, 937 (1986).
[2]M. V. Berry, Proc. Roy. Soc. London, Ser. A **392**, 45 (1984).
[3]R. Y. Chiao and Y.-S. Wu, Phys. Rev. Lett. **57**, 933 (1986).
[4]The use of a series of mirrors to simulate the optical fiber was suggested independently by J. N. Ross, private communication.
[5]W. W. Chow *et al.*, Rev. Mod. Phys. **57**, 61 (1985).