Berry’s Phase

1 Aim of the Experiment

Studying the Pancharatnam-Berry (also called as geometrical) phase for polarized light. By a simple arrangement with interference of light, and using polarizers, one will able to observe the shift in fringe pattern and hence validate the Berry’s Phase.

2 Introduction

The Pancharatnam-Berry phase is a geometric phase associated with the polarization of light. When the polarization of a beam traverses a closed loop on the Poincaré sphere, the final state differs from the initial state by a phase factor equal to half of the area encompassed by the loop upon the sphere.

The Poincaré sphere is a space used to uniquely represent each state of polarization, as shown in Fig. 1. By convention, the north and south poles are taken to be the states of circular polarization, and points on the equator correspond to linear polarization of different orientations with diametrically opposite points being orthogonal to each other. Points on the northern and southern hemispheres correspond to elliptically polarized light of different handedness.

![Poincaré sphere](image)

Figure 1: Poincaré sphere representing various polarization states.

By transforming the polarization of an input beam following a closed path on the Poincaré sphere the wave acquires a geometric phase. It is important to note that we can vary the phase by changing the state of polarization without changing the optical path length. Changing the optical path length introduces dynamical phases.
3 Theory

In his paper, Pancharatnam considered the phase of a beam of light whose state of polarization is varied. His central result, when expressed symmetrically, concerned a beam that is returned to its original state of polarization via two intermediate polarizations. He showed that the phase does not return to its original value but increases by $\Omega/2$, where $\Omega$ is the solid angle subtended on the Poincaré sphere by the geodesic triangle whose vertices are the three polarizations. Therefore, two light beams of different polarization $P_1, P_2$ have a phase difference if they are resolved by an analyzer $P$. The Pancharatnam phase is proportional to the solid angle $\Omega$ of the triangle $P_1, P_2, P$ on the Poincaré sphere.

4 Experiment

The linearly polarized light coming out of the He-Ne laser corresponds to a point on the equator of the Poincaré sphere. After passing through the (properly oriented) quarter wave plate, it gets transformed to circular polarization. Say right circular (RCP). After any reflection, either from a mirror or a beam splitter, the helicity changes, so RCP becomes left circular (LCP) and vice versa. After passing through a sequence of reflections and transmissions in the interferometer, we obtain two beams, one LCP and the other RCP. They are made to interfere on a beam splitter, but will show an interference pattern only when we project out the same linear component by passing them through a linear analyzer. In other words, the two beams from the N-pole and the S-pole are brought back to a point on the equatorial plane of the Poincaré sphere (linearly polarized light).

The axis of the analyzer determines the angle of the linearly polarized light coming out of it. If the orientation of the analyzer is vertical, then the two LCP and RCP beams will come back to the same point (A) as the initial vertically-polarized beam. Thus, there is no additional phase. But if the axis of the analyzer makes an angle with respect to the vertical, then the state of the final beam (linearly polarized) will be different, represented by the point B. Therefore we expect that if we rotate the analyzer axis by 180° it will
shift by one fringe.

For the Berry’s phase experiment, we use a Mach-Zehnder interferometer with an extra mirror in one of the arms. The schematic diagram of the arrangement is shown in Fig. 3.

1. Verify that the light coming out of the laser is linearly polarized by rotating the analyzer and checking that the light intensity is lowest when the analyzer is making an angle of 90° with the polarization axis.

2. Find the optic axis of the Quarter wave plate by looking for similar maximum and minimum in intensity with the analyzer. Align the wave plate so that there is an angle of 45° between its optic axis and the polarization axis of the laser (found in the previous step). This will convert linear polarization to circular. Verify this using the analyzer: the intensity should be the same when the analyzer is rotated by any angle.

3. Build an interferometer as shown in the figure. There should be no interference fringes without the analyzer because the two beams are orthogonally polarized. But you should see fringes when the analyzer is introduced.

4. Measure the angle by which the analyzer has to be rotated to shift the fringe pattern from one maximum to the next.

5 Precautions

1. DO NOT TOUCH ANY OPTICAL ELEMENT WITH YOUR FINGERS. IT IS IMPOSSIBLE TO CLEAN FINGERPRINTS. HANDLE ONLY THE BASE.

2. Use beam stoppers and check for back reflected light from beam splitters and polarizers in order to avoid damage to the eye.
3. Make sure that the two beams are propagating in a parallel direction after the second beam splitter so that you have good fringes.

4. Properly mark the reference fringe so that you can measure the fringe shift accurately.

5. Avoid backlash error by rotating the analyzer in only one direction always.