Circular and Linear States of Light Polarization

In general, light is elliptically polarized with its electric field rotating either clock-wise or counter-clock-wise to form an ellipse perpendicular to the direction of light propagation. In certain special conditions, such an ellipse can become a circle (major and minor axis of the ellipse have the same length) or even a line (when one of the axis of the ellipse is zero). In this experiment, you will learn i) how to rotate linearly polarized light by $90^\circ$ and ii) how to convert linearly to circularly polarized light. Those actions will come from a special optical component called waveplate, which is a uniaxial crystal that creates a phase change between two orthogonal directions (one along the crystalline axis, another perpendicular to it) as light propagates through the waveplate. In this experiment you will use a half-wave plate $\Delta \varphi = \pi = \frac{2\pi}{\lambda_0} d (n_e - n_o)$ and a quarter-wave plate $\Delta \varphi = \frac{\pi}{2} = \frac{2\pi}{\lambda_0} d (n_e - n_o)$

Experiment:

1. Rotating linearly polarized by $90^\circ$:

Set two linear polarizers (leave some space in between them) in the optical path of a laser beam so that their transmission axes are parallel to each other. Place a detector in front of the exiting optical beam. By measuring the power intensity after the beam have crossed both polarizers, you can align the polarizers by searching for the maximum intensity in the photo detector. Now, without disturbing the polarizers, set between them a half-wave plate with its fast axis
at about 45° with respect to the direction of linear polarization defined by the linear polarizers (see Figure below). Fine tune the fast axis of the half-wave plate by searching for a minimum of the transmitted light going into the detector while you adjust the HWP. Under this configuration the light wave propagating after the HWP is linearly polarized but the electric field (and magnetic) has rotated by 90° with respect to the polarization after the first polarizer. This configuration is useful for transforming vertically polarized light into horizontally polarized light (and vice versa).

1.a) Remove the second polarizer from the optical path, leave undisturbed the other parts of the previous setup. Place a linear polarizer mounted on a rotation mount after the HWP (see Figure below) and keep the detector to collect the light intensity after the second linear polarizer.
Take intensity measurements evenly spaced over $0^\circ - 360^\circ$ for the axis of transmission of the rotating linear polarizer. Tabulate your results.

1.b) Now, remove the HWP (see Figure below) and take intensity measurements evenly spaced over $0^\circ - 360^\circ$ for the axis of transmission of the rotating linear polarizer. Tabulate your results and verify if there is a shift of about $90^\circ$ in the orientation of the light polarization between the two data sets you obtained.

2. Converting linearly to circularly polarized light:

See schematic setup in Figure below. Set a beam splitter tilted at about $45^\circ$ to split an optical beam. Adjust a linear polarizer in the optical path. Set the quarter-wave plate with its fast axis at about $45^\circ$ with respect to the direction of transmission of the linear polarizer. Set a mirror in front of the propagating beam for retroflection.
The reflected light reaching the detector has crossed twice the QWP which then functions as a HWP and will rotate the polarization by 90°. Due the 90° rotation of the light polarization, the first polarizer will block the propagation of the reflected light. Fine tune the alignment of the fast axis of the quarter wave plate by searching for a minimum of the reflected light going into the detector. (This configuration works as an optical isolator where the light is transmitted in only one direction; it is highly useful in experimental setup that needs to avoid back reflected signals).

Under the configuration above the light wave propagating after the QWP in the forward direction is circularly polarized. Remove the mirror and the beam splitter from the optical path; leave undisturbed the other parts of the previous setup. Place a linear polarizer mounted on a rotating mount after the QWP (see Figure below). Place the detector to collect the light intensity after the rotating linear
polarizer.

Take intensity measurements evenly spaced over $0^\circ - 360^\circ$ for the axis of transmission of the rotating linear polarizer. Tabulate your results.

**Analysis:**

Plot all your tabulated data. Compare your results. Did you get a perfect $90^\circ$ rotation in Part 1? If light is truly circularly polarized, one would expect a constant intensity as you rotate the linear polarizer in Part 2? Did you obtain such behavior? If not, why?

**Questions to consider:**

1. Can we rotate the polarization by other angles rather than $90^\circ$?

2. Circular polarization can be clock-wise or counter-clock wise. How can we select one or the other?