QUARTER & HALF WAVE PLATE - KSCIQWP

1. Key Concepts

- Electromagnetic wave
- Birefringence
- Polarisation

2. Introduction

Light, when modelled as a wave phenomenon, can be classified as a transverse electromagnetic wave comprising of oscillating electric and magnetic fields that are oriented perpendicular to each other. Depending on the orientation of the plane of polarization of the electric field with respect to the direction of propagation of the wave, the wave can be classified as polarised or un-polarized. If the plane of polarization of electric field is fixed with respect to the direction of propagation, then the wave is said to be linearly polarized. If the plane of polarisation rotates as the wave propagates, then the wave is said to be elliptically or circularly polarised.

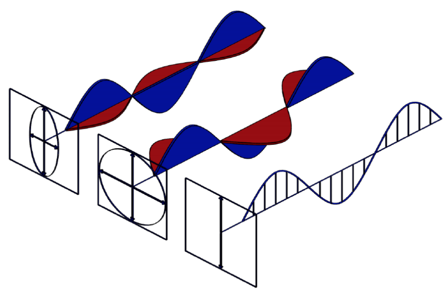


Figure 1: Elliptical, circular and linear polarization states of E-M radiation.

3. Objective

To study the effect of wave plates on polarised light

- Quarter-wave plate
- Half-wave plate

4. Theory

When light travels through a transparent material for example a crystal, it interacts with the atoms in the lattice of the crystal. As a result, the speed of light inside the crystal is slower than that in a vacuum or air. The speed of light v in the crystal varies inversely with the refractive index (R.I) n of the crystal. Due to its transmission through the crystal, the light also undergoes a phase shift (phase delay/retardation) . For a light of wavelength, travelling a path of length inside

a crystal having a refractive index , the phase delay is given by equation (1).

$$\phi = \frac{2\pi}{\lambda} nL---(1)$$

If in a given crystal, if all the crystallographic axes are identical i.e ($a = b = c$). The light experiences an isotropic environment. For such a crystal with a R.I of n, the light will experience the same value of R.I through out the crystal, irrespective of the direction of propagation through the crystal. Therefore, the speed of light will be the same in all directions of travel in the crystal and will accumulate the same phase delay. Such materials having the same value R.I through are called *opticallyisotropic* materials. (example: glass, ice ..).

4.1 Birefringence

There are a class of crystals that exhibit different value of R.I depending on the crystallographic axes. Such type of crystals are called *opticallyanisotropic* materials. This property is also called as *birefringence* and the materials are called *birefringentmaterial*. Owing to different value of R.I in the material. The speed of light is different in different directions. Generally, a ray of light entering a birefringent material splits into two components: an ordinary ray along the ordinary axis (O) and an extraordinary ray along the extraordinary axis (E). The value of the R.I will be different along the ordinary axis and the extraordinary axis, generally indicated by $n_o n_e$ respective.

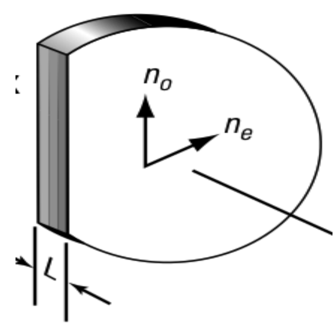


Figure 1: Representation of birefringent material

Since, the speed of the light inside the crystal is different along the ordinary and the extraordinary axes. There will be phase difference between the ordinary and the extraordinary ray. As, a birefringent material introduce a phase difference between the two components of the electric field incident(of the incident light) on it. They are used in optical devices called ***retarders.***

4.2 Retarders (wave plate)

Retarders are optical devices that resolves a light wave into two orthogonal linear polarization components by producing a phase shift between them. The transmitted light may have a different type of polarization than the incident beam due to the induced phase difference.

(**Note:** Retarders do not polarize the unpolarized light incident on it and ideally,they do not reduce the intensity of the incident light.)

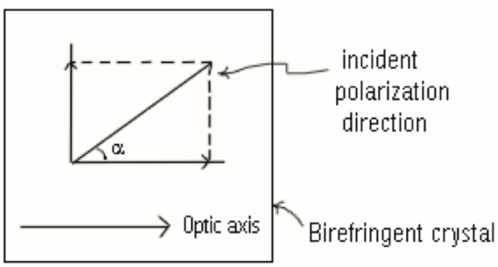


Figure 2: Splitting of linearly polarized light into two components as it enters a birefringent crystal.

In figure 3, we can see the arbitrary phase shift/difference between the two components of the E vector of ordinary and extraordinary ray resulting in elliptical polarization after these rays transmit through a retarder (wave plate).

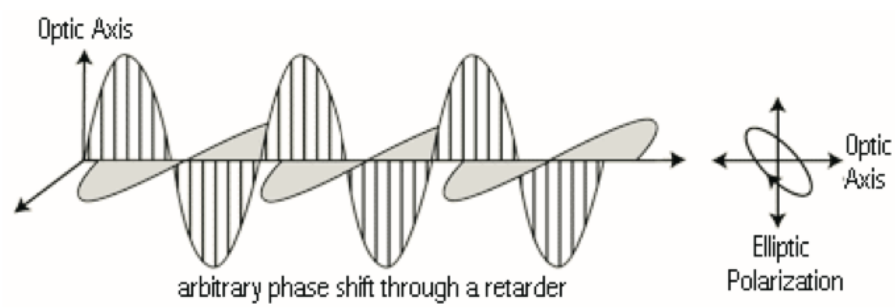


Figure 3: Conversion of linear polarization to elliptical polarization.

The phase difference between the ordinary ray and the extraordinary ray depend on the following factors:

- Wavelength of the incident light.

- The value of R I along both the axes.

- The thickness of the material (optical path length).

Commonly used retarders are quarter wavelength plate$\left(\frac{\lambda}{4}\right)$ and half wavelength plate $\left(\frac{\lambda}{2}\right)$.

Quarter-wave plate: It is used to convert a linearly polarised input beam into a circular (or elliptical) polarised beam and vice-versa. In a circular polarised light, the magnitude of the two components on the electric field($\vec{E}$) must be and the phase difference between the two components should be $90°$ or $270°$. The quarter-wave plate produces a phase difference of $90°$ between the two components of the incident light. It also depends on the angle of orientation between the incident linearly polarised light and the optics axis of the birefringence crystal. When the angle between the linearly polarised light and the optical axis is $(\alpha = 45°)$. The output light becomes circularly polarized.

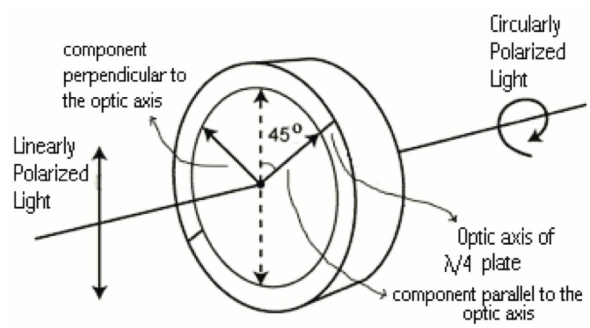


Figure 4: Conversion between linear and circular polarization by a quarter-wave plate.

When a circularly polarised light is incident on the quarter-wave plate. The output light is linearly polarised and is oriented at an angle of $(45°)$ with respect to the optical axis of the birefringent material.

Half-wave plate: Rotates the plane of polarization of linearly polarised light that is input on it by twice the angle between its optical axis and the initial orientation of the linearly polarised light.

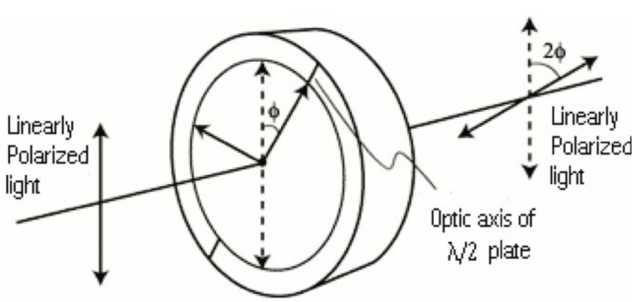


Figure 5: Rotation of linear polarization by a half-wave plate

The phase difference between the ordinary and the extraordinary ray is given by the following relation.

$$\phi = \frac{2\pi}{\lambda}(n_0 - n_e)L$$

5.Equipment

S.No	Equipment	Code	Quantity
1	Optical Bench Set 0.8m	KSCIOB1	1
2	Light Source Holder	KSCIHA001	1
3	Polarizer Holder	KSCIHA004	1
4	Analyzer Holder	KSCIHA006	1
5	Half Wave Plate	KSCIHA031	1
6	Quarter Wave Plate	KSCIHA030	1
7	Light Sensor Holder	KSCIHA510	1
8	Regulated DC Power Supply	KSCIPSLS	1
9	Data Processor	KSCIDP1	1

6. Safety Instruction

Components like horizontal bench and power supply are heavy. Take adequate safety measures while handling them.

Never look directly at the laser beam.

7. Experimental setup

- Place the optical bench on a stable horizontal surface such as a sturdy table top and make sure the bench is parallel to the horizontal surface using the adjustable mounts.
- Mount the light source securely on the upright, place the upright on the optical bench and lock the slide screw on the slider,Mount the polarizer stage on the upright, place it adjacent to the light source (along the optical path) and lock the slide screw on the slider.
- Mount the analyzer on the upright, place it adjacent to the polarizer and lock the slide screw on the slider.
- Mount the light sensor on the upright and place it adjacent to the analyzer. Connect the light sensor to the data processor.
- Ensure that the light source, polarizer, analyzer and the light sensor are all aligned in the same optical axis.

8. Experiment

- Power up the light source and the data processor.
- Keep the voltage supplied to the light source constant throughout the experiment.
- Do not change the filter throughout the experiment.

8.1 Quarter wavelength plate

1. Switch on the light source and adjust it to a constant illumination. Keep the power supplied to the light source constant throughout the experiment.
2. Set the axis of the polarizer to 0°.
3. First, without introducing the quarter wavelength plate into the set up. Adjust the polariser or the analyzer such that light of minimum intensity is emerging out of the analyser. (analyser and polariser axes are perpendicular to each other).

4. Now, introduce the quarter wavelength plate in-between the polariser and analyser and make sure all of them are accurately aligned along the optical axis of the setup.

5. Rotate the analyser in steps of $10°$ for one full rotation and record the angle of the analyser (θ) and the change in intensity. Tabulate your readings.

6. Convert the angle into radian and compute $cos^2\theta$

7. Draw the following graphs

   a. Intensity vs θ

   b. Intensity vs $cos^2\theta$

8.1.2 Quarter wavelength plate (alternate method)

The quarter wavelength plate experiment can also be by the following method.

1. Switch on the light source and adjust it to a constant illumination. Keep the power supplied to the light source constant through out the experiment.

2. Set the axis of the polariser to $0°$.

3. First, without introducing the quarter wavelength plate into the set up. Adjust the polariser or the analyser such that light of minimum intensity is emerging out of the analyser. (analyser and polariser axes are perpendicular to each other).

4. Now, introduce the quarter wavelength plate in-between the polariser and analyser and make sure all of them are accurately aligned along the optical axis of the setup.

5. Rotate and set the quarter wavelength plate to $30°$ and keep it constant.

6. Rotate the analyser in steps of $0°$ for one full rotation and record the angle of the analyser (θ) and the change in intensity. Tabulate your readings.

7. Repeat step 6 for the following orientations of the quarter wavelength plate ($30°$, $60°$, and $90°$). Tabulate your readings.

8.2 Half wavelength plate

(**NOTE**: if you don't have a half wavelength plate. You can use two quarter wavelength plates placed next to each other aligned to the same orientation to do the experiment)

1. Switch on the light source and adjust it to a constant illumination. Keep the power supplied to the light source constant through out the experiment.

2. Set the axis of the polariser to $0°$.

3. First, without introducing the half wavelength plate into the set up. Adjust the polariser or the analyser such that light of minimum intensity is emerging out of the analyser. (analyser and polariser axes are perpendicular to each other).

4. Now, introduce the half wavelength plate in-between the polariser and analyser and make sure all of them are accurately aligned along the optical axis of the setup.

5. Rotate the analyser in steps of 10° for one full rotation and record the angle of the analyser (θ) and the change in intensity. Tabulate your readings.

6. Convert the angle into radian and compute $cos^2\theta$

7. Draw the following graphs

   a. Intensity vs θ

   b. Intensity vs $cos^2\theta$

9. Tabular column

9.1 Quarter wavelength plate

Angle of the analyser ($\boldsymbol{\theta}$)	Light intensity	$\boldsymbol{\theta}$ in radian	$\boldsymbol{cos^2\theta}$
0			
10			
20			
30			

9.1.1 Quarter wavelength plate (alternate method)

Angle of the analyser ($\boldsymbol{\theta}$)	Light intensity in lux			
	Angle of QWP= 0°	Angle of QWP= 30°	Angle of QWP= 60°	Angle of QWP= 0°
0				
10				
20				

Angle of the analyser (θ)	Light intensity in lux			
30				

9.2 Half wavelength plate

Angle of the analyser (θ)	Light intensity	θ in radian	$cos^2\theta$
0			
10			
20			
30			

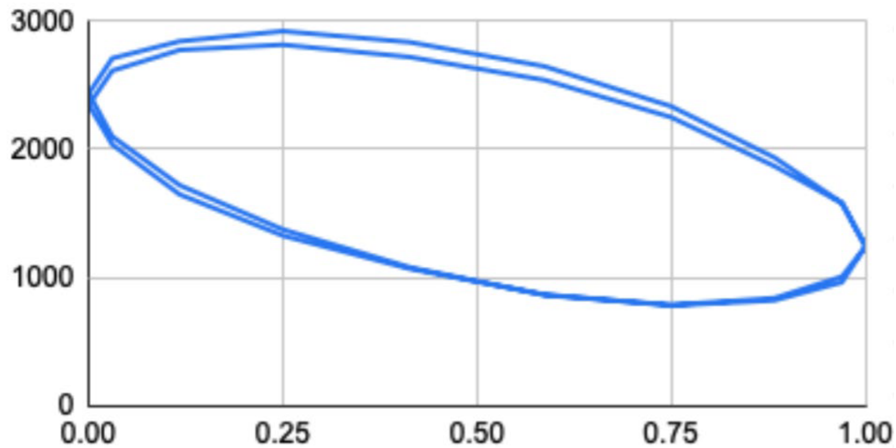
10. Sample results and analysis

10.1 Quarter wavelength plate

θ in deg	Light intensity in lux	θ in radian	$cos^2\theta$
0	1236	0	1
10	1005	0.1745329252	0.9698463104
20	837	0.3490658504	0.8830222216
30	784	0.5235987756	0.75
40	861	0.6981317008	0.5868240888
50	1078	0.872664626	0.4131759112
60	1373	1.047197551	0.25
70	1719	1.221730476	0.1169777784
80	2100	1.396263402	0.03015368961
90	2436	1.570796327	0

θ in deg	Light intensity in lux	θ in radian	$cos^2\theta$
100	2710	1.745329252	0.03015368961
110	2843	1.919862177	0.1169777784
120	2922	2.094395102	0.25
130	2836	2.268928028	0.4131759112
140	2647	2.443460953	0.5868240888
150	2335	2.617993878	0.75
160	1935	2.792526803	0.8830222216
170	1581	2.967059728	0.9698463104
180	1240	3.141592654	1
190	961	3.316125579	0.9698463104
200	820	3.490658504	0.8830222216
210	780	3.665191429	0.75
220	865	3.839724354	0.5868240888
230	1067	4.01425728	0.4131759112
240	1325	4.188790205	0.25
250	1647	4.36332313	0.1169777784
260	2037	4.537856055	0.03015368961
270	2346	4.71238898	0
280	2613	4.886921906	0.03015368961
290	2775	5.061454831	0.1169777784
300	2816	5.235987756	0.25
310	2720	5.410520681	0.4131759112
320	2540	5.585053606	0.5868240888
330	2250	5.759586532	0.75
340	1868	5.934119457	0.8830222216

θ in deg	Light intensity in lux	θ in radian	$cos^2\theta$
350	1579	6.108652382	0.9698463104
360	1251	6.283185307	1



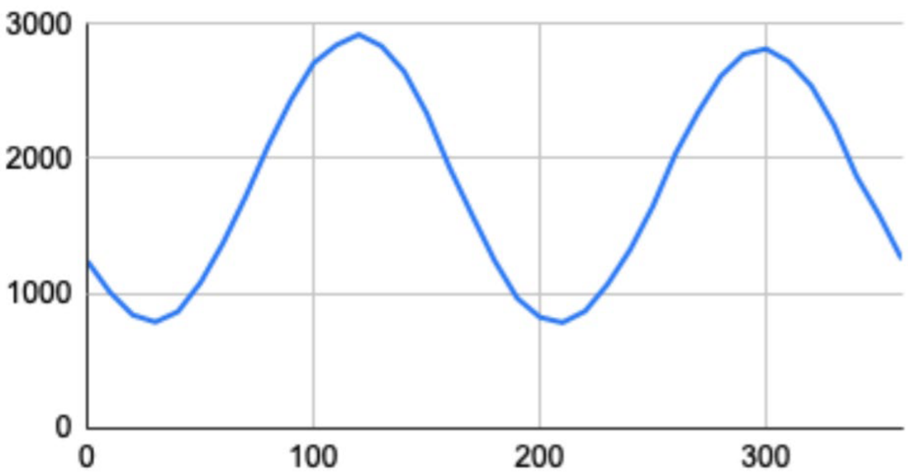


Figure 7: Plot of intensity vs the angle for a quarter wavelength plate intensity on the Y- axis, angle θ on the X-axis.

Form the graph in the figure we can that the input linearly polarised is converted into a elliptically polarised light. (see the theory and figure 3).

10.2 Half wavelength plate

θ in deg	Light intensity in lux	θ in radian	$cos^2\theta$
0	7	0	1
10	64	0.1745329252	0.9698463104
20	245	0.3490658504	0.8830222216
30	688	0.5235987756	0.75
40	1185	0.6981317008	0.5868240888
50	1763	0.872664626	0.4131759112
60	2305	1.047197551	0.25
70	2750	1.221730476	0.1169777784
80	3044	1.396263402	0.03015368961
90	3241	1.570796327	0
100	3173	1.745329252	0.03015368961
110	2895	1.919862177	0.1169777784
120	2529	2.094395102	0.25
130	1997	2.268928028	0.4131759112
140	1432	2.443460953	0.5868240888
150	846	2.617993878	0.75
160	399	2.792526803	0.8830222216
170	156	2.967059728	0.9698463104
180	10	3.141592654	1
190	58	3.316125579	0.9698463104
200	328	3.490658504	0.8830222216
210	691	3.665191429	0.75
220	1185	3.839724354	0.5868240888
230	1762	4.01425728	0.4131759112
240	2300	4.188790205	0.25

θ in deg	Light intensity in lux	θ in radian	$cos^2\theta$
250	2700	4.36332313	0.1169777784
260	3010	4.537856055	0.03015368961
270	3123	4.71238898	0
280	3070	4.886921906	0.03015368961
290	2834	5.061454831	0.1169777784
300	2453	5.235987756	0.25
310	1906	5.410520681	0.4131759112
320	1370	5.585053606	0.5868240888
330	853	5.759586532	0.75
340	461	5.934119457	0.8830222216
350	150	6.108652382	0.9698463104
360	11	6.283185307	1

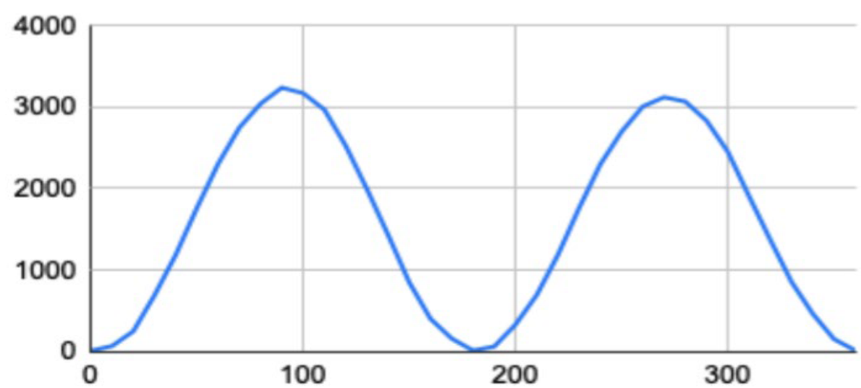


Figure 9: Plot of intensity vs the angle for a half wavelength plate intensity on the Y- axis, angle θ on the X-axis.

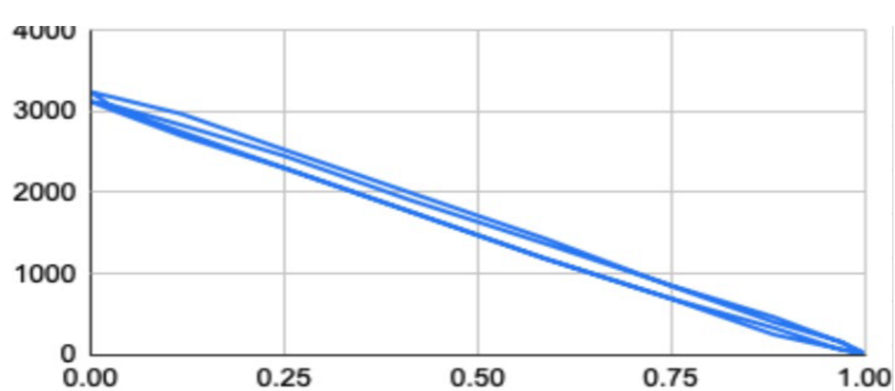


Figure 10: Plot of intensity vs for the half wavelength plate. Intensity on the Y- axis and $cos^2\theta$ on the x axis.

Here, we can see that the half wavelength plate acts like a polarization rotator.

10.3 Comparison of quarter wavelength plate and polarizer.

We can see from figure 11 that there is a phase difference between quarter wavelenght plate and polariser is clearly evident. This gives us insight into the birefringence property of the quarter wave length plate.

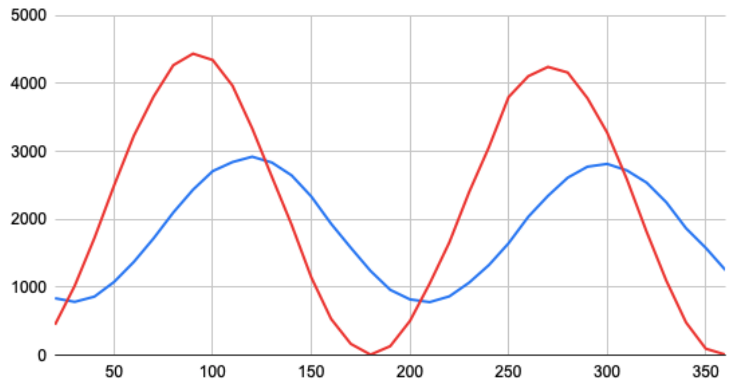


Figure 11: A plot of intensity (Y -axis) and angle of the analyser (X-axis)

Red :- Quarter wavelength plate
Blue :- polarizer

10.4 Quarter wavelength plate (alternate method)

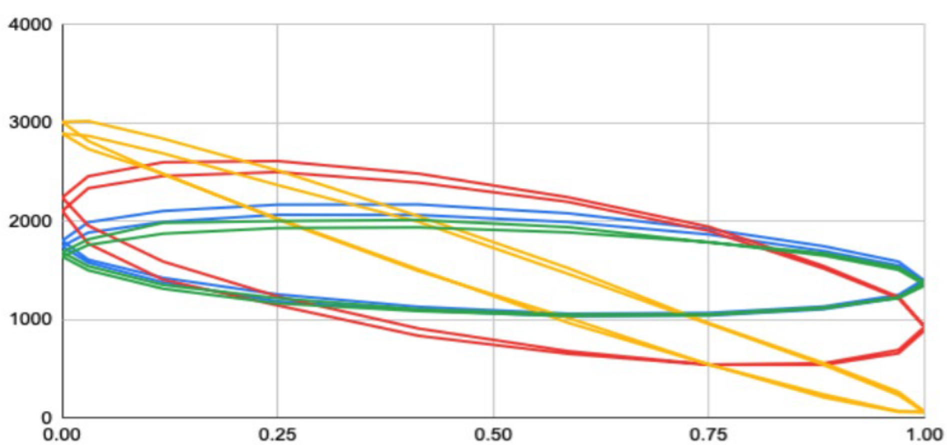


Figure 13: A plot of intensity (Y-axis) vs $cos^2\theta$ (X-axis). For different orientations of Quarter wavelength plate.(QWP)
Blue curve:-with out QWP, red curve - QWP at 0° and 90° orientation, orange curve:- QWP at 30°, and green curve:- QWP at 60°

11. References

1. Principle of birefringence: Microscopy U
2. Eugene Hecht, Optics, 4th. Ed, 2001, Addison-Wesley.

From the figure 13, we can see clearly that the linearly polarised light that is incident on a QWP is converted into an elliptically/circularly polarized light.