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**Optics and photonics — Lasers  
and laser-related equipment —  
Measurement of phase retardation of  
optical components for polarized laser  
radiation**

*Optique et photonique — Lasers et équipements associés aux lasers  
— Mesurage du retard de phase des composants optiques pour le  
rayonnement laser polarisé*

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## Foreword

ISO (the International Organization for Standardization) is a worldwide federation of national standards bodies (ISO member bodies). The work of preparing International Standards is normally carried out through ISO technical committees. Each member body interested in a subject for which a technical committee has been established has the right to be represented on that committee. International organizations, governmental and non-governmental, in liaison with ISO, also take part in the work. ISO collaborates closely with the International Electrotechnical Commission (IEC) on all matters of electrotechnical standardization.

The procedures used to develop this document and those intended for its further maintenance are described in the ISO/IEC Directives, Part 1. In particular, the different approval criteria needed for the different types of ISO documents should be noted. This document was drafted in accordance with the editorial rules of the ISO/IEC Directives, Part 2 (see [www.iso.org/directives](http://www.iso.org/directives)).

Attention is drawn to the possibility that some of the elements of this document may be the subject of patent rights. ISO shall not be held responsible for identifying any or all such patent rights. Details of any patent rights identified during the development of the document will be in the Introduction and/or on the ISO list of patent declarations received (see [www.iso.org/patents](http://www.iso.org/patents)).

Any trade name used in this document is information given for the convenience of users and does not constitute an endorsement.

For an explanation of the voluntary nature of standards, the meaning of ISO specific terms and expressions related to conformity assessment, as well as information about ISO's adherence to the World Trade Organization (WTO) principles in the Technical Barriers to Trade (TBT), see [www.iso.org/iso/foreword.html](http://www.iso.org/iso/foreword.html).

This document was prepared by Technical Committee ISO/TC 172, *Optics and Photonics*, Subcommittee SC 9, *Laser and electro-optical systems*, in collaboration with the European Committee for Standardization (CEN) Technical Committee CEN/TC 123, *Lasers and photonics*, in accordance with the agreement on technical cooperation between ISO and CEN (Vienna Agreement).

This second edition cancels and replaces the first edition (ISO 24013:2006), which has been technically revised.

The main changes are as follows:

- [6.3.3](#) was amended to add an additional step requiring that a transmitting optic be aligned so that its optical axis is horizontal;
- [Clauses 2](#) and [6.1](#) were amended to reflect that ISO 14644-1:1999 does not need the year;
- [6.3.1](#),  $(\pi/4 \pm 2)$  mrad was changed to  $\pi/4$  rad  $\pm$  2 mrad;
- [7.1](#) and [8.1](#) were updated to account for phase retardances close to  $\pi$ .

Any feedback or questions on this document should be directed to the user's national standards body. A complete listing of these bodies can be found at [www.iso.org/members.html](http://www.iso.org/members.html).

## Introduction

Normally it is desirable that the state of polarization be not influenced by the optical components used. For the generation or maintenance of specific states of polarization the influence of optical components on the beam polarization is crucial. For generating circularly polarized radiation from linearly polarized radiation  $\pi/2$  phase retarders are used.

This document describes methods to determine the relative phase retardation of optical components with respect to the X- and Y-axes of the polarization and s- and p-polarization, respectively. This document is necessary for optics manufacturers, suppliers and customers of such optics for the determination of the influence of phase retardation of optical components.

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# Optics and photonics — Lasers and laser-related equipment — Measurement of phase retardation of optical components for polarized laser radiation

## 1 Scope

This document specifies test methods for the determination of the linear optical phase retardation of optical components by polarized laser beams.

## 2 Normative references

The following documents are referred to in the text in such a way that some or all of their content constitutes requirements of this document. For dated references, only the edition cited applies. For undated references, the latest edition of the referenced document (including any amendments) applies.

ISO 11145, *Optics and photonics — Lasers and laser-related equipment — Vocabulary and symbols*

ISO 12005, *Lasers and laser-related equipment — Test methods for laser beam parameters — Polarization*

## 3 Terms and definitions

For the purposes of this document, the terms and definitions given in ISO 11145 and ISO 12005 apply.

ISO and IEC maintain terminological databases for use in standardization at the following addresses:

- ISO Online browsing platform: available at <https://www.iso.org/obp>
- IEC Electropedia: available at <https://www.electropedia.org/>

## 4 Symbols and abbreviated terms

**Table 1 — Symbols used and units of measure**

Symbol	Term	Unit
$p_L$	degree of linear polarization	1
$\phi$	angle of analyser	rad
$a_1$	amplitude of electric field in X-direction	V/m
$a_2$	amplitude of electric field in Y-direction	V/m
$a, b$	principal axes of the polarization ellipse	V/m
$\delta$	phase difference	rad
$\Delta\delta$	phase retardation	rad
$E$	electric field vector amplitude	V/m
$P$	radiant power	W
$\alpha_X$	absorptance in X-direction	1
$\alpha_Y$	absorptance in Y-direction	1
$\psi$	angle of the principle axis of the polarization ellipse	rad

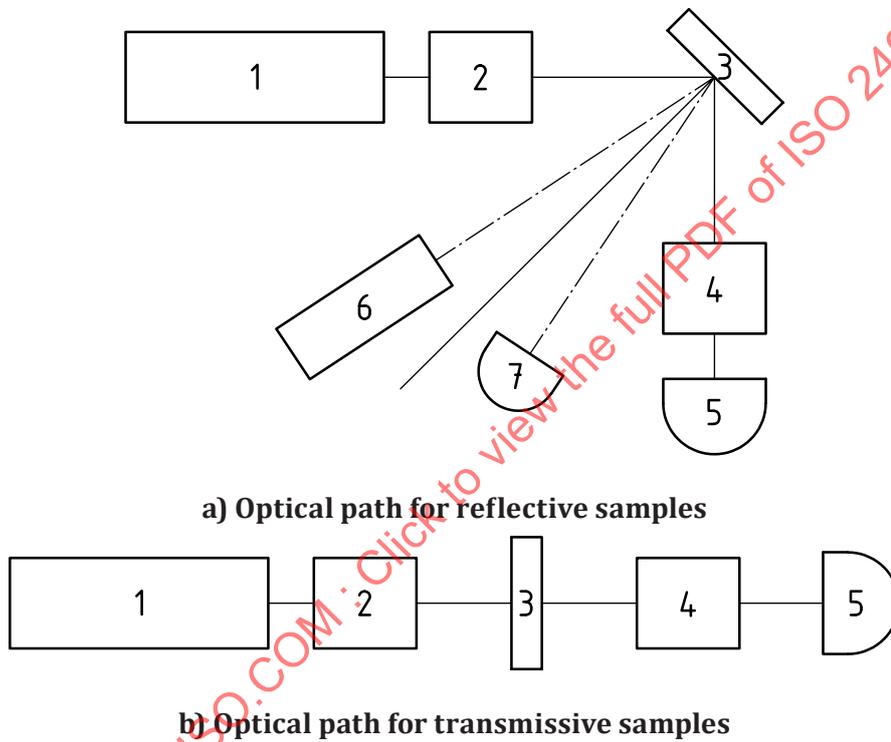
### 5 Measurement principle

The optical component under test is irradiated by a laser beam with a defined state of polarization. After passing the component the state of polarization of the beam is determined by using an analyser. The phase retardation is then evaluated from the change of the state of polarization.

There are two cases to distinguish:

- a) the expected phase retardation is near zero: in this case a circularly polarized beam shall be used for the test;
- b) the expected phase retardation is near  $\pi/2$ : in this case a linearly polarized beam shall be used for the test.

Figure 1 shows the measuring set up.



**Key**

- 1 radiation source
- 2 polarizer (linear or circular)
- 3 sample under test
- 4 analyser
- 5 detector
- 6 alignment laser
- 7 positional sensitive detector

**Figure 1 — Schematic drawing of the measuring set up**

A laser and a polarizer generating linearly or circularly polarized radiation shall be used in combination with an analyser and a power detector. For measuring reflective samples an alignment laser in combination with a positional sensitive detector ensures a reproducible angle alignment of the sample under test.

## 6 Preparation of test sample and measuring arrangement

### 6.1 General

Storage, cleaning and the preparation of the test samples are carried out in accordance with the manufacturer's instructions for normal use.

The environment of the testing place consists of dust-free filtered air with between 40 % and 60 % relative humidity. It is recommended that the residual dust be reduced in accordance with, for example, the clean-room ISO class 7 as specified in ISO 14644-1.

A linearly polarized and monochromatic source, such as a laser, shall be used as the radiation source. To keep errors as low as possible, the beam power stability should be as high as possible.

Wavelength, angle of incidence and state of polarization of the laser radiation used for the measurement shall correspond to the values specified by the manufacturer for the use of the test sample. If ranges are accepted for these three quantities, any combination of wavelength, angle of incidence and state of polarization may be chosen from these ranges.

### 6.2 Laser beam preparation

The accuracy of the measurement is strongly influenced by a clear definition of the state of polarization of the laser beam. Therefore, it is necessary to prepare the polarization state of the probe beam (linearly or circularly) carefully.

If the expected phase retardation is near  $\pi/2$ , a linearly polarized beam shall be used. The quantity  $(1 - p_L)$ , where  $p_L$  is the degree of linear polarization, shall be less than  $10^{-3}$ . This shall be verified by using the analyser without the sample in the beam path.

NOTE 1 Such a state of polarization can be achieved by using a linearly polarized laser beam in combination with additional polarizing elements.

If the expected phase retardation is near zero, a circularly polarized beam shall be used. The degree of linear polarization  $p_L$  shall be less than  $10^{-3}$ . This shall be verified by using the analyser without the sample in the beam path.

NOTE 2 Such a state of polarization can be achieved by using a linearly polarized laser beam in combination with additional linearly polarizing elements and a  $\pi/2$  phase retarding element.

All optical elements shall not increase the quantity  $(1 - p_L)$  in the case of a linearly polarized beam and  $p_L$  in the case of a circularly polarized beam, by more than  $10^{-3}$ . For this reason, the use of folding mirrors in the test setup is discouraged and all other optical elements shall be used under normal incidence.

### 6.3 Sample adjustment and system calibration

#### 6.3.1 Reflective samples

The sample shall be mounted very accurately at the angle of incidence according to the manufacturer's specification. The deviation from the intended angle of use shall be less than 2 mrad. For this purpose the component shall be mounted on a precision rotary stage. Back reflecting the laser beam into the laser cavity defines the normal incidence.

Additionally, in the case of a linearly polarized probe beam, the angle between the direction of polarization of the incoming laser beam and the plane of incidence shall be  $\pi/4$  rad  $\pm$  2 mrad.

### 6.3.2 Possible alignment procedure

First, the laser beam shall be adjusted so that the beam propagation is parallel to the surface of the optical table. Second, the beam reflected from the sample shall be adjusted so that the propagation of the reflected beam is also parallel to the surface of the optical table for all angles of incidence. Third, in case of a linearly polarized incoming beam, the angle between the direction of polarization and the plane of the optical table shall be adjusted to be  $\pi/4$  rad. This can be achieved by adjusting the linear polarizer initially so that the direction of polarization is parallel to the optical table. This can be checked by using a Brewster window, the turning axis of which is perpendicular to the optical table. If under these conditions the reflected minimum power is propagating parallel to the optical table, then turning of the linear polarizer by  $\pi/4$  rad finally provides the desired angle of the linearly polarized beam.

When the alignment has been calibrated according to the procedure described above, the correct alignment of the additional samples can be simplified by using an additional laser with high pointing stability and a positional sensitive detector (see [Figure 1](#)). In this case the additional laser beam hits the component under near-normal incidence and the adjustment of the sample under test is performed so that the reflected laser beam hits the positional sensitive detector at the same position.

### 6.3.3 Transmissive samples

The sample shall be mounted under the angle of incidence according to the manufacturer's specification. The deviation from the intended angle of use shall be less than 2 mrad.

The sample shall be rotated so that its optical axis is horizontal (parallel to the optical table) within 2 mrad. This may be achieved by setting the polarizer so that the direction of polarization is horizontal, setting the analyser to  $\pi/2$  rad, and rotating the sample until there is a minimum signal measured by the detector.

## 6.4 Detection system

### 6.4.1 General

The detection system consists of a polarization analyser and a power detector.

### 6.4.2 Polarization analyser

To determine the state of polarization of the laser beam after passing the test sample a polarization analyser mounted on a rotary stage is necessary.

The analyser shall be capable of characterizing the state of polarization of the laser beam after passing across the additional polarizer with the specified accuracy (see [6.2](#)).

### 6.4.3 Power detector

To ensure that the entire beam hits the detector area, the detector width should be at least twice the beam diameter.

A high dynamic range of the signal to noise ratio is required for the low noise detector since this directly influences the resolution. Furthermore, the detector characteristics shall be linear over a wide signal range since this directly influences the accuracy of the measurements.

NOTE Silicon detectors for the visible and near infrared spectral range as well as pyroelectric detectors for the infrared spectral range can meet these specifications.

## 7 Test procedure

### 7.1 Test procedure for zero or $\pi$ phase retardation

#### 7.1.1 General

If the expected phase retardation is near zero or  $\pi$ , the polarization of the probe beam shall be circularly polarized. This shall be achieved by using a linearly polarized laser in combination with a quarter-wave plate or similar means. Before the test the state and the degree of this circular polarization shall be measured and recorded. The initial state of polarization is characterized by (see also [Annex A](#)).

$$\cos \delta = \frac{P(45^\circ) - P(135^\circ)}{2\sqrt{P(90^\circ)P(0^\circ)}} \quad (1)$$

where  $P \propto E^2$  is the detector signal magnitude.

#### 7.1.2 Simple test procedure for zero absorbance difference

In the case of no absorbance difference, it is sufficient to measure the detector signals at two analyser positions,  $45^\circ$  and  $135^\circ$ . The phase difference is then given by

$$\cos \delta = \frac{P(45^\circ) - P(135^\circ)}{P(45^\circ) + P(135^\circ)} \quad (2)$$

#### 7.1.3 Test procedure for non zero absorbance difference

If there is a difference in the absorbance for the two polarization components it is sufficient to measure the detector signal at four analyser positions,  $0^\circ$ ,  $45^\circ$ ,  $90^\circ$  and  $135^\circ$ . The phase difference is given by [Formula \(1\)](#).

The relative difference in the absorbance is then given by

$$\frac{P(90^\circ)}{P(0^\circ)} = \left( \frac{a_2}{a_1} \right)^2 \quad \frac{a_2}{a_1} = \sqrt{\frac{1-a_Y}{1-a_X}} \quad (3)$$

### 7.2 Test procedure for $\pi/2$ phase retardation

#### 7.2.1 General

If the expected phase retardation is near  $\pi/2$ , the polarization of the probe beam shall be linear. Before the test, the state and the degree of this linear polarization shall be measured and recorded. The initial state of polarization is characterized by a curve fit to the function given by [Formula \(A.4\)](#).

#### 7.2.2 Simple test procedure for zero absorbance difference

In the case of no absorbance difference, it is sufficient to measure the detector signals at two analyser positions,  $45^\circ$  and  $135^\circ$ . The phase difference is then given by [Formula \(2\)](#).

#### 7.2.3 Test procedure for non zero absorbance difference

If there is a difference in the absorbance for the two polarization components it is sufficient to measure the detector signal at four analyser positions,  $0^\circ$ ,  $45^\circ$ ,  $90^\circ$  and  $135^\circ$ . The phase difference is given by [Formula \(1\)](#).

The relative difference in the absorbance is then given by [Formula \(3\)](#).

## 8 Evaluation

### 8.1 General

The initial phase difference of the probe beam shall be evaluated according to 7.1 and 7.2, respectively, using [Formula \(1\)](#). The phase retardation shall be evaluated by subtracting the phase difference before the sample from the phase difference after the sample. If the phase difference is expected to be near zero or  $\pi/2$ , the phase retardation is given by

$$\Delta\delta = \delta_{\text{after sample}} - \delta_{\text{before sample}} \quad (4)$$

If the phase difference is expected to be near  $\pi$ , the phase retardation is given by

$$\Delta\delta = \delta_{\text{after sample}} - \delta_{\text{before sample}} + \pi \quad (5)$$

### 8.2 Evaluation for zero phase retardation

#### 8.2.1 Evaluation for zero absorptance difference

The phase retardation caused by the test sample is given by the difference of the measured phase difference of the probe beam [without test sample, see [Formula \(1\)](#)] and the measured phase difference after passing the test sample [see [Formula \(2\)](#)].

#### 8.2.2 Evaluation for non-zero absorptance difference

The phase retardation caused by the test sample is given by the difference of the measured phase difference of the probe beam [without test sample, see [Formula \(1\)](#)] and the measured phase difference after passing the test sample (see 7.1.3). Additionally, the relative absorptance difference can be determined according to [Formula \(3\)](#).

### 8.3 Evaluation for $\pi/2$ phase retardation

#### 8.3.1 Evaluation for zero absorptance difference

The phase retardation caused by the test sample is given by the difference of the measured phase difference of the probe beam [without test sample, see [Formula \(1\)](#)] and the measured phase difference after passing across the test sample [see [Formula \(2\)](#)].

#### 8.3.2 Evaluation for non-zero absorptance difference

The phase retardation caused by the test sample is given by the difference of the measured phase difference of the probe beam [without test sample, see [Formula \(1\)](#)] and the measured phase difference after passing the test sample (see 7.1.3). Additionally, the relative absorptance difference can be determined according to [Formula \(3\)](#).

## 9 Test report

The following information shall be included in the test report:

- a) General information
  - 1) test has been performed in accordance with ISO 24013:2023;
  - 2) date of test;
  - 3) name and address of test organization;

- 4) name of individual performing the test.
- b) Information concerning the test sample
- 1) type of sample;
  - 2) manufacturer;
  - 3) manufacturer's model designation;
  - 4) serial number.
- c) Test conditions
- 1) laser wavelength(s);
  - 2) laser parameter settings:
    - output power or energy;
    - current or energy input.
  - 3) polarization;
  - 4) environmental conditions:
    - temperature;
    - humidity;
- d) Information concerning testing and evaluation
- 1) test method used;
  - 2) detector and sampling system:
    - response time of the detector system;
    - trigger delay of sampling (for pulsed lasers only);
    - measuring time interval (for pulsed lasers only).
  - 3) beam forming optics and attenuating method:
    - type of attenuator;
    - type of beam splitter;
    - type of focusing element.
  - 4) other optical components and devices used for the test (polarizer, monochromator, etc);
  - 5) other relevant parameters or characteristics of the test which have to be chosen (aperture setting, reference plane, reference axis, laboratory system);
  - 6) measured phase retardation  $\Delta\delta$
  - 7) uncertainty of measurement.

## Annex A (informative)

### Theoretical background

#### A.1 Description of a polarized wave

An arbitrarily polarized electro-magnetic wave propagating in the Z-direction (see Reference [2]) is described by the components of the electric field along the X, Y, and Z directions

$$E_X = a_1 \cos(\tau + \delta_1)$$

$$E_Y = a_2 \cos(\tau + \delta_2)$$

$$E_Z = 0$$

(A.1)

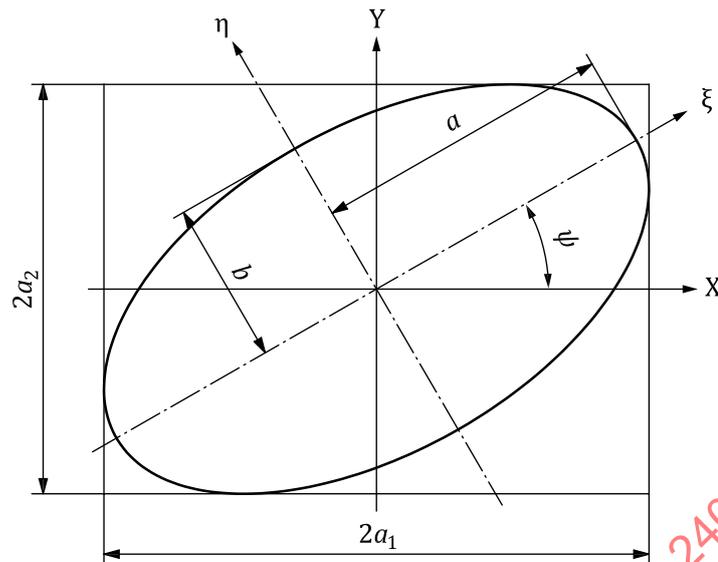
where

$a_1$  and  $a_2$  are the amplitudes in the X- and Y-directions;

$\tau$  is the variable part of the phase factor;

$\delta_1$  and  $\delta_2$  are the constant part of the phase factor.

The state of polarization is generally represented by the polarization ellipse for the electric vector as shown in [Figure A.1](#).

**Key**

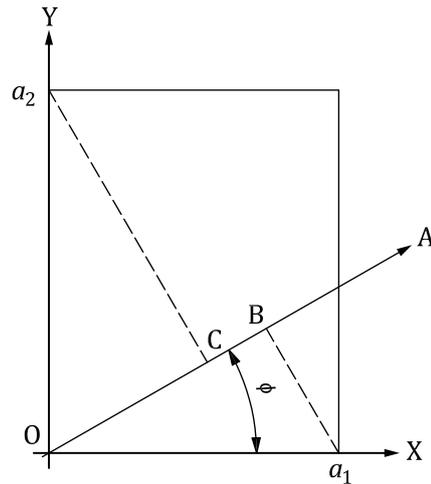
$a$	amplitude of electric field along principal axis of the polarization ellipse	$X, Y$	coordinate axes of the absolute coordinate system
$b$	amplitude of electric field along principal axis of the polarization ellipse	$\xi, \eta$	coordinate axes of the principal coordinate system
$a_1$	amplitude of electric field in X-direction	$\psi$	angle between the principal axis of the polarization ellipse and the X-axis
$a_2$	amplitude of electric field in Y-direction		

**Figure A.1 — Polarization ellipse of a polarized wave**

In the general case the polarization is represented by an ellipse with amplitudes  $a$  and  $b$  along axes  $\xi$  and  $\eta$ , respectively, where the principal axes  $\xi$  and  $\eta$  are rotated about the reference axes  $X$  and  $Y$ , respectively by the angle  $\psi$ . The state of polarization is either described by  $a, b$  and  $\psi$  or by  $a_1, a_2$  and  $\delta$ , where  $\delta = \delta_2 - \delta_1$ .

**A.2 Analysing the state of polarization**

For analysing the state of polarization an analyser is rotated through the beam to be characterized. The analyser transmits only the part of the electric field orientated in the same direction as the analyser as shown in [Figure A.2](#).



**Key**

- |       |   |        |   |
|-------|---|--------|---|
| X, Y  | coordinate axes of the absolute coordinate system | B      | point of intersection of the perpendicular to A to $a_1$ with A |
| $a_1$ | amplitude of electric field in X-direction        | C      | point of intersection of the perpendicular to A to $a_2$ with A |
| $a_2$ | amplitude of electric field in Y-direction        | O      | origin of the coordinate system                                 |
| A     | direction of the analyser                         | $\phi$ | angle between the analyser and the X-axis                       |

**Figure A.2 — Transmitted light at an analyser**

Of the electric field with the amplitudes  $a_1$  and  $a_2$  in the X- and Y-direction respectively, only the components parallel to the analyser are transmitted. The angle between the analyser and the X-direction is given by  $\phi$ . These components are OB and OC that are given by [Formula \(A.2\)](#):

$$OB = a_1 \cos \phi \quad OC = a_2 \sin \phi \tag{A.2}$$

The measured signal on the detector after the analyser is directly proportional to  $E^2$ . It is obtained from the interference of these two monochromatic waves with the phase difference,  $\delta$ , by [Formula \(A.3\)](#):

$$E^2 = E_x^2 + E_y^2 + 2\sqrt{E_x^2 E_y^2} \cos \delta \tag{A.3}$$

With the amplitudes given by [Formula \(A.2\)](#) this yields to

$$\frac{E^2(\phi)}{a_1^2} = \cos^2 \phi + \left(\frac{a_2}{a_1}\right)^2 \sin^2 \phi + \frac{a_2}{a_1} \sin(2\phi) \cos \delta \tag{A.4}$$

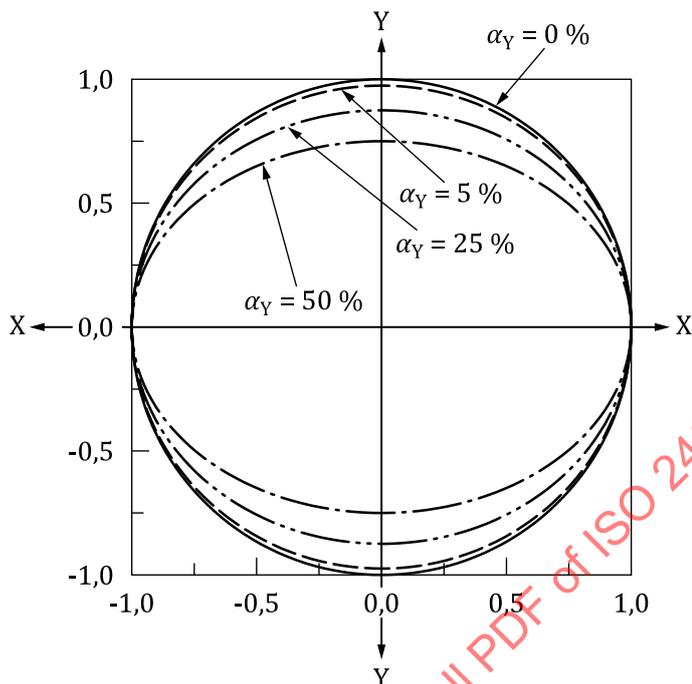
The signal on the detector for different angles  $\phi$  of the analyser is described by [Formula \(A.4\)](#).

**A.3 Influence of absorption**

In the case of absorbing samples the beam before the analyser should ideally be circularly polarized for samples with phase retardations both near zero and near  $\pi/2$ . A difference in the absorption of the electric field between the X- and Y-direction does not affect the phase difference  $\delta$  of the components of the electric field but changes their amplitudes. [Figure A.3](#) and [Figure A.4](#) show the effect of the absorption, where the absorption in the Y-direction is assumed to be greater than zero and the absorption in the X-direction is assumed to be zero.

The change in the modulation of the detector signal after the analyser does not result from a phase retardation (the phase difference remains at  $\pi/2$ ) but from a change in the amplitudes of the two

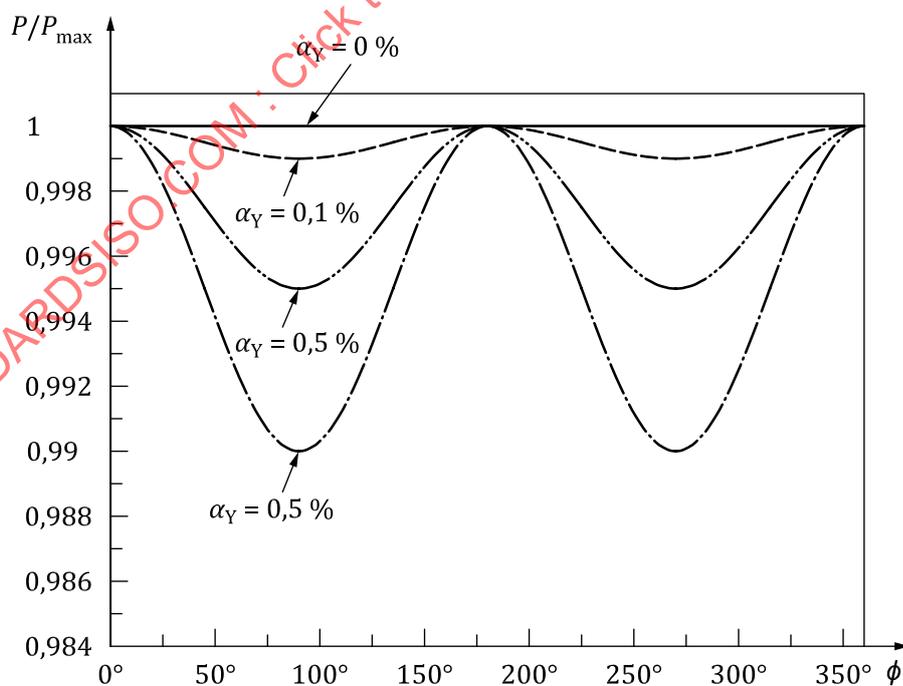
components of the electric field vector. The maxima of the detector signal are at  $0^\circ$  and  $180^\circ$  for a greater absorption in the y-direction are at  $90^\circ$  and  $270^\circ$  for a greater absorption in the X-direction.



**Key**

X, Y coordinate axes of the absolute coordinate system  $\alpha_Y$  absorptance in Y-direction

**Figure A.3 — Influence of absorptance difference on polarization ellipse**



**Key**

$\phi$  angle between the analyser and the X-axis  $\alpha_Y$  absorptance in Y-direction  
 $P/P_{max}$  normalized detector signal

**Figure A.4 — Influence of absorptance difference on detector signal**

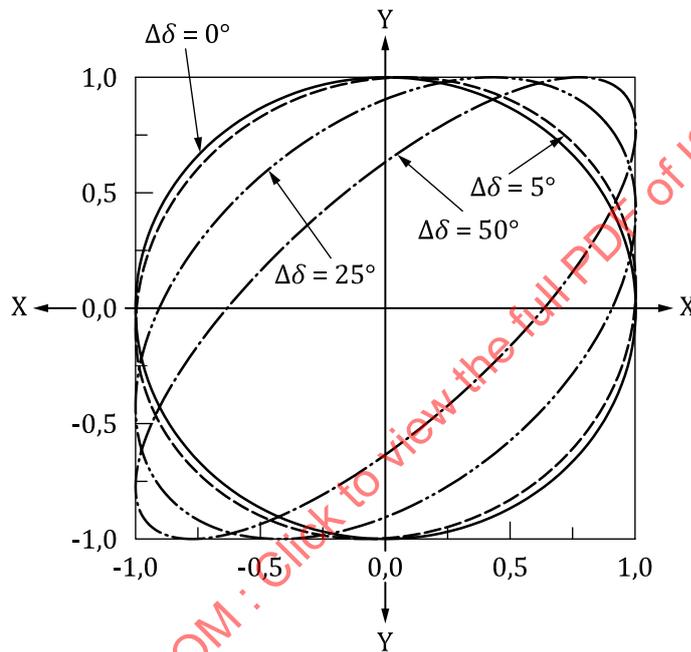
### A.4 Influence of phase retardation

A pure phase retardation with the absence of a difference of the absorption does not affect the amplitudes of the incident wave. Since the ratio of the amplitudes in the X- and Y-direction remains constant the angle,  $\psi$ , of the incident wave does not change. The phase retardation  $\Delta\delta$  induces a deformation of the polarization ellipse as seen in [Figure A.5](#).

The phase retardation is given by the difference of the phase difference after and before the sample.

$$\Delta\delta = \delta_{\text{after sample}} - \delta_{\text{before sample}} \tag{A.5}$$

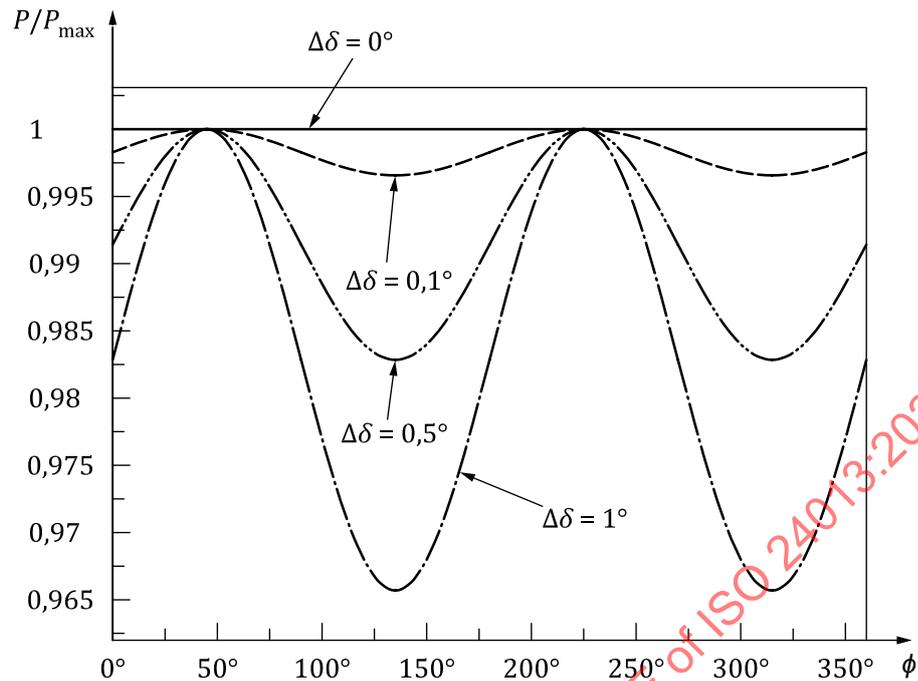
According to [Figure A.6](#) the maxima of the detector signals are recognized at  $45^\circ$  and  $225^\circ$  for a phase retardation larger than zero, while the maxima are located at  $135^\circ$  and  $315^\circ$  for a phase retardation smaller than zero.



**Key**

X, Y coordinate axes of the absolute coordinate system     $\Delta\delta$  phase retardation

**Figure A.5 — Influence of phase retardation on polarization ellipse**

**Key**

$\phi$  angle between the analyser and the X-axis       $\Delta\delta$  phase retardation  
 $P/P_{\max}$  normalized detector signal

**Figure A.6 — Influence of phase retardation on detector signal**

### A.5 Influence of absorption and phase retardation

The simultaneous presence of absorption and phase retardation results in a modulation of the detector signal and a change of the angle  $\psi$  as shown in [Figure A.7](#). [Formula \(A.4\)](#) includes the influence of the absorption and the phase retardation.