Elementy optroniki
#5

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Równania fali elektromagnetycznej

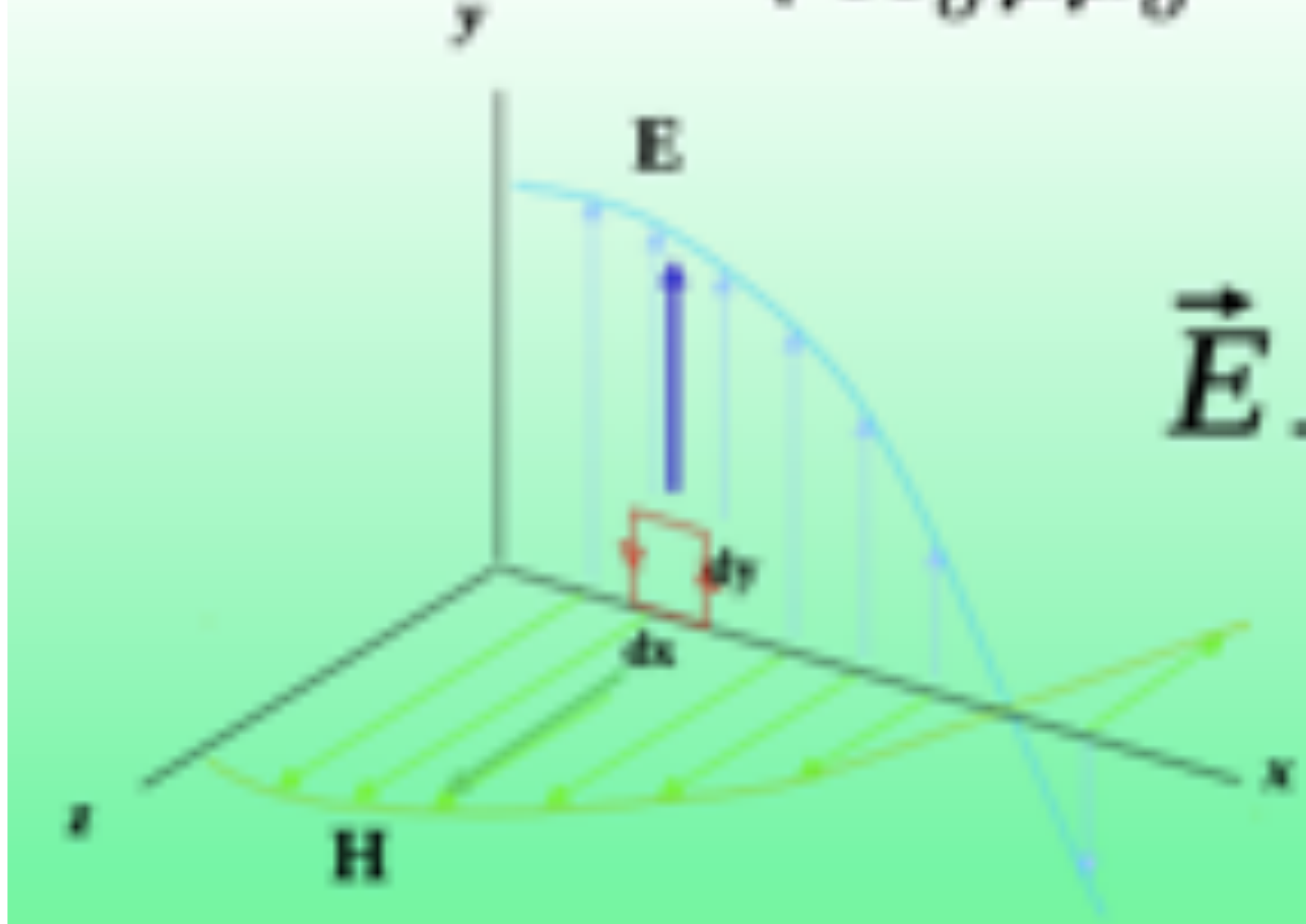
$$\nabla^2 \vec{E} = \varepsilon\varepsilon_0 \mu\mu_0 \frac{\partial \vec{E}}{\partial t}$$

$$\nabla^2 \vec{H} = \varepsilon\varepsilon_0 \mu\mu_0 \frac{\partial \vec{H}}{\partial t}$$

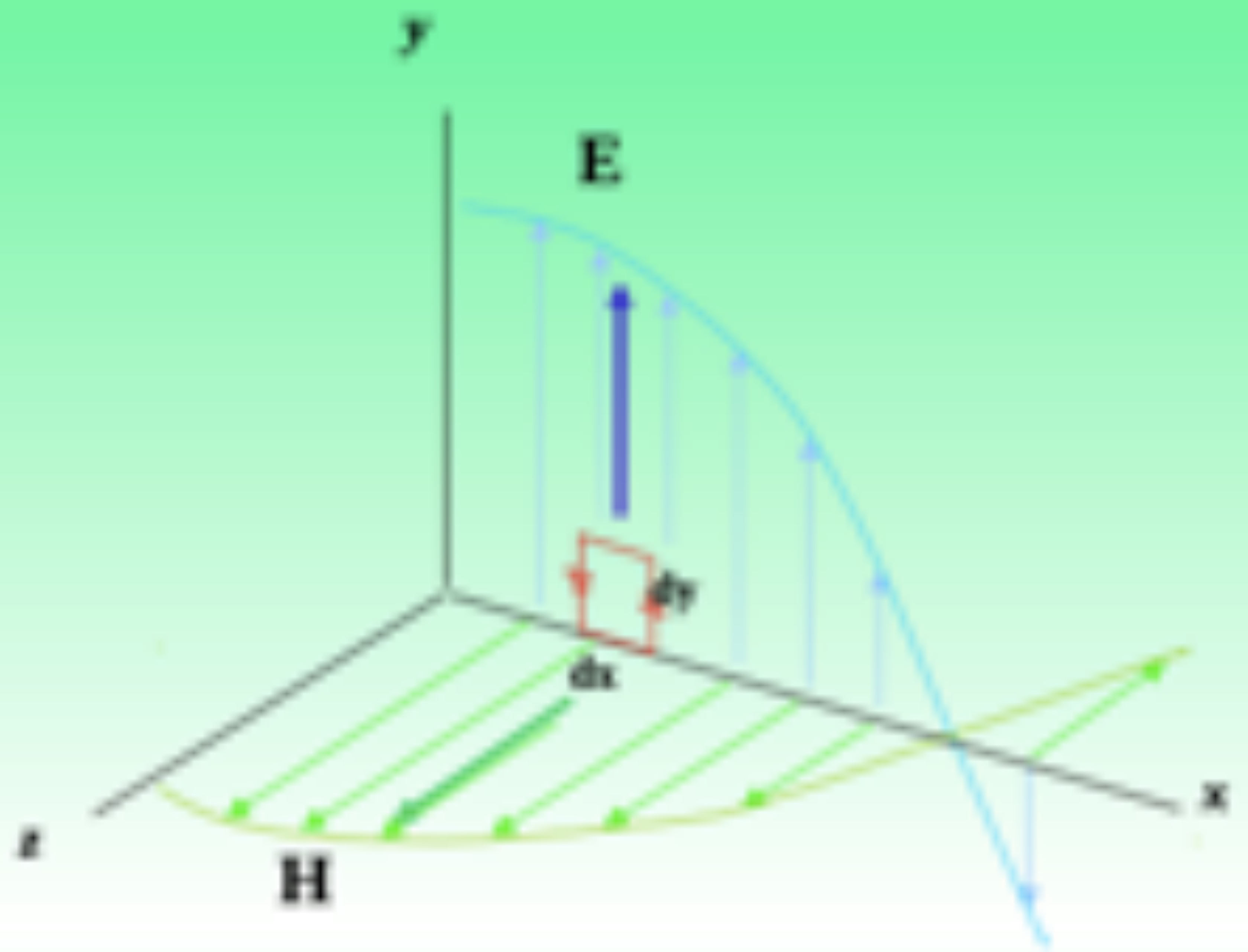
$$\longrightarrow \quad \nabla^2 \vec{E} = \frac{1}{\upsilon^2} \frac{\partial^2 \vec{E}}{\partial t^2}$$

Równania falowe dla fali elektromagnetycznej o prędkości fazowej υ.

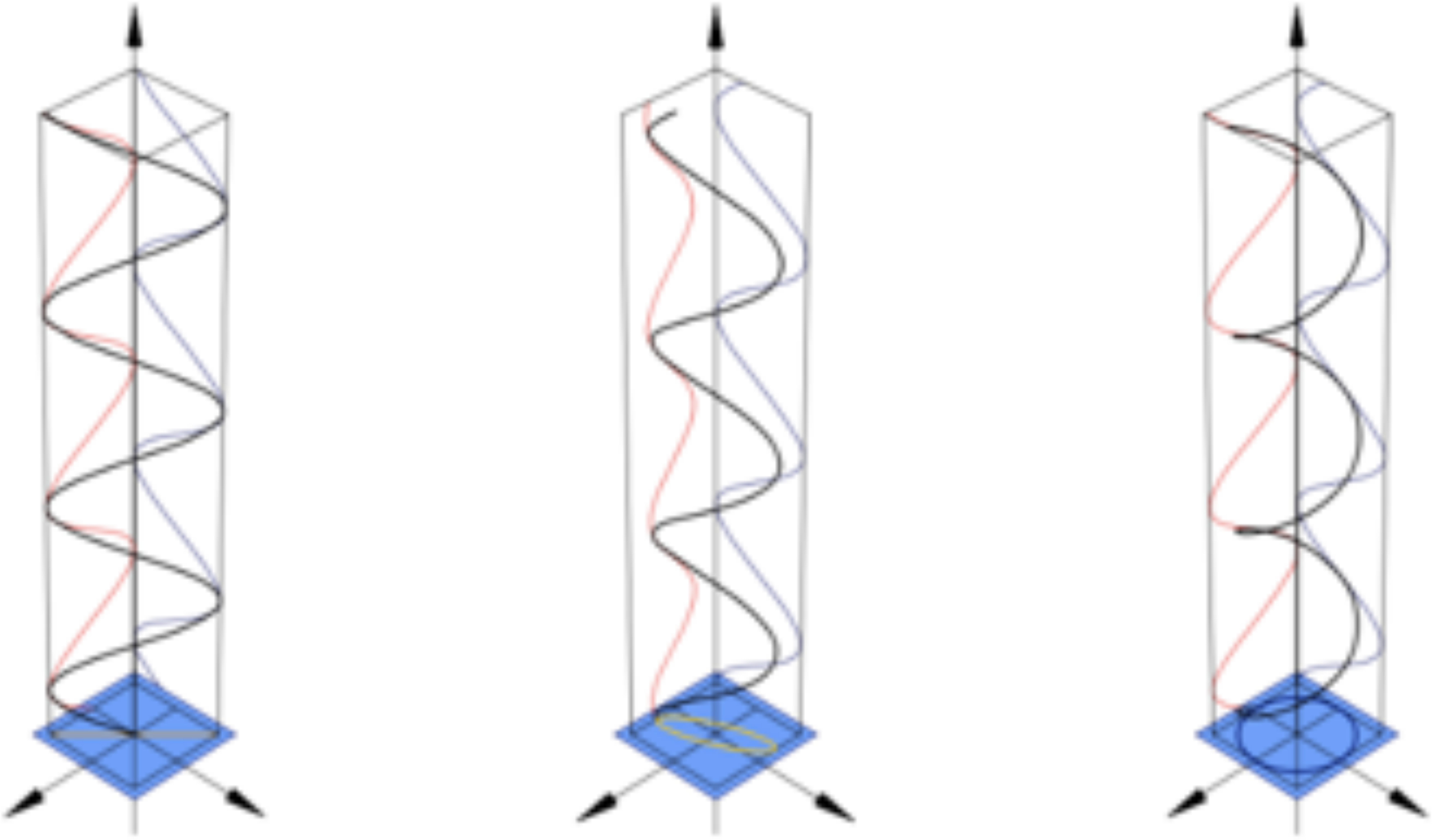
$$\upsilon = \frac{1}{\sqrt{\varepsilon\varepsilon_0 \mu\mu_0}} \qquad \upsilon_{vac} = c = \frac{1}{\sqrt{\varepsilon_0 \mu_0}} \qquad \upsilon_{os} = \frac{c}{\sqrt{\varepsilon\mu}}$$

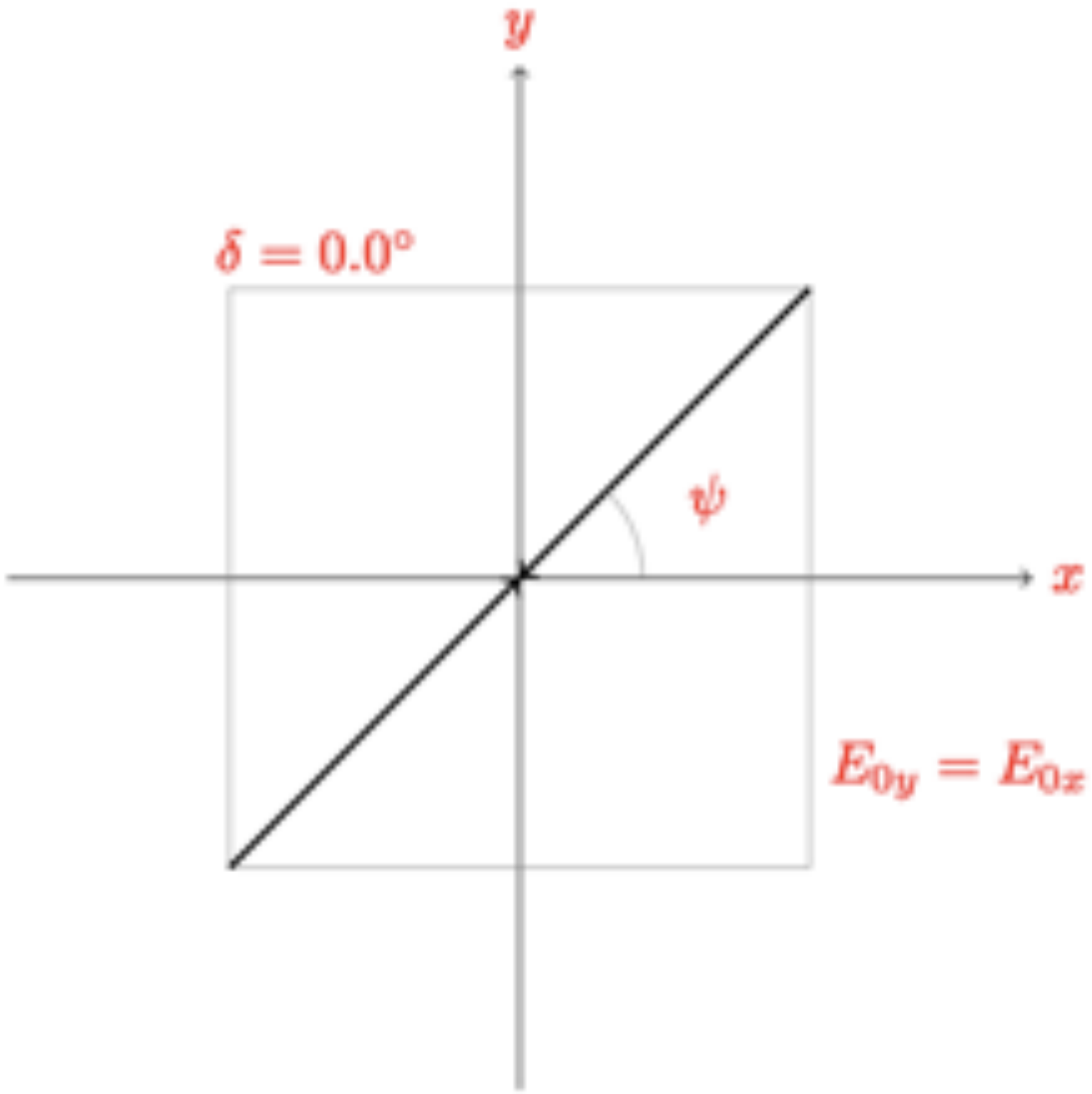


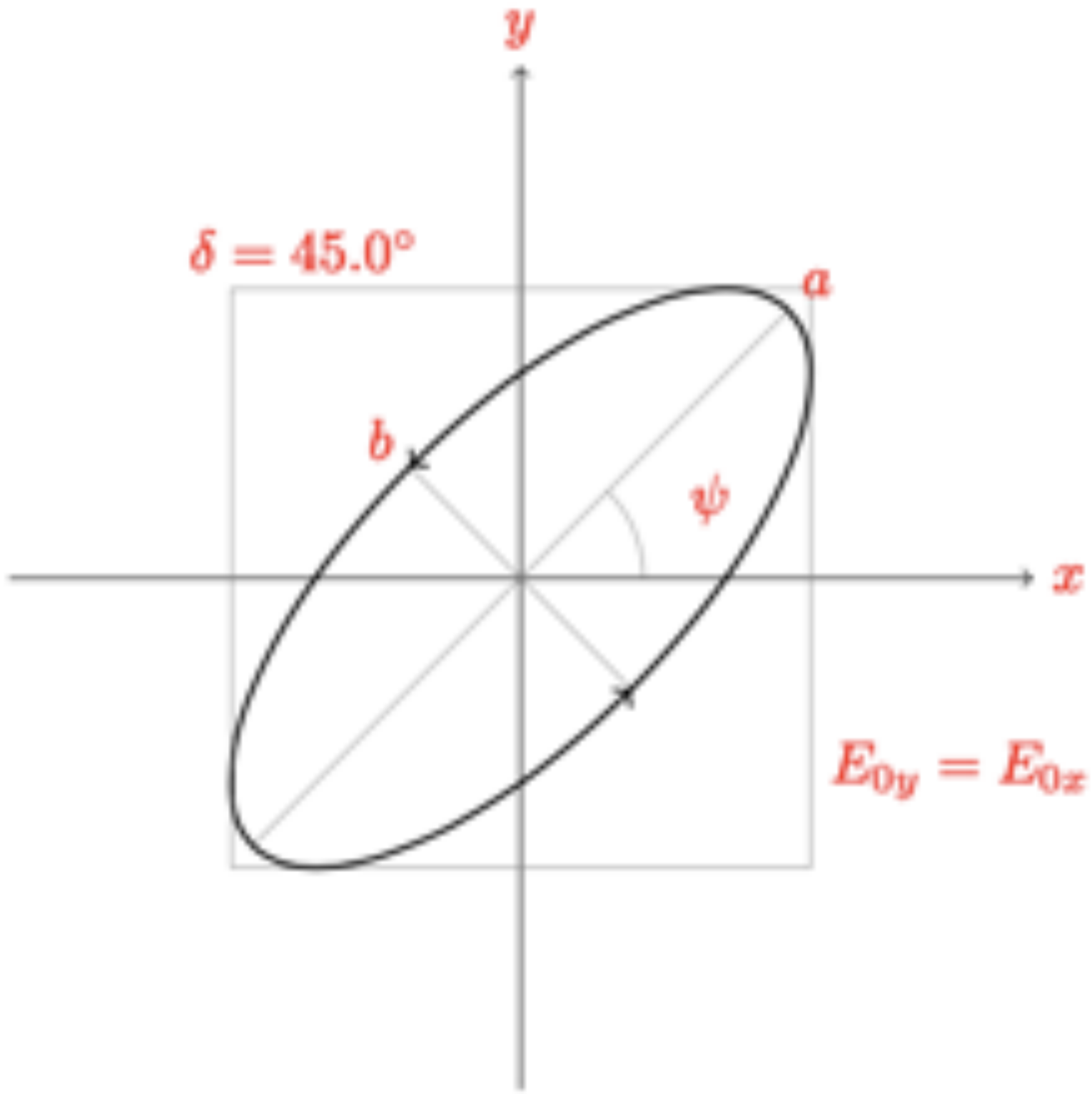
$$\vec{E} \perp \vec{H} \cap \vec{E} \perp \vec{k} \cap \vec{H} \perp \vec{k}$$

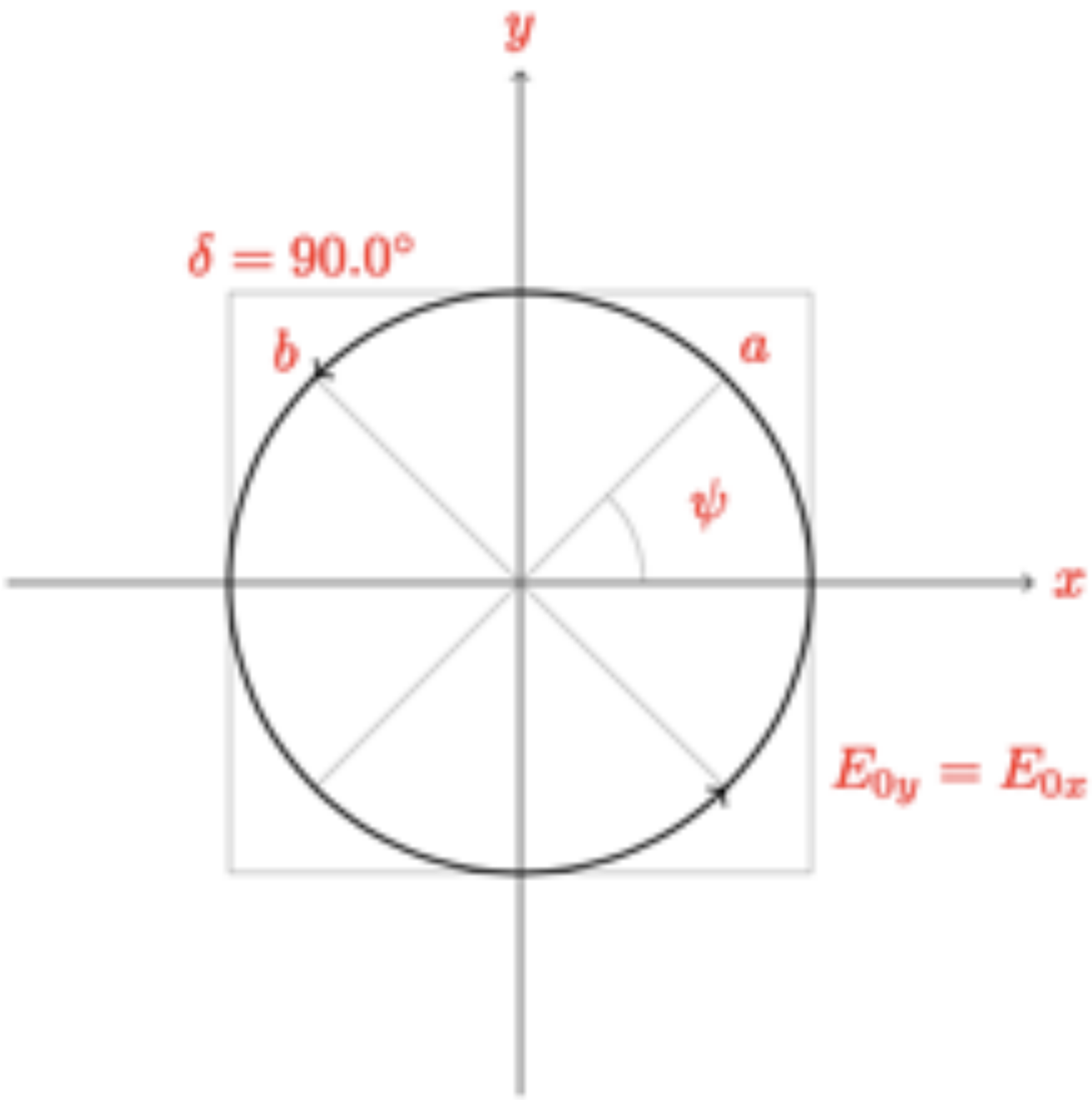


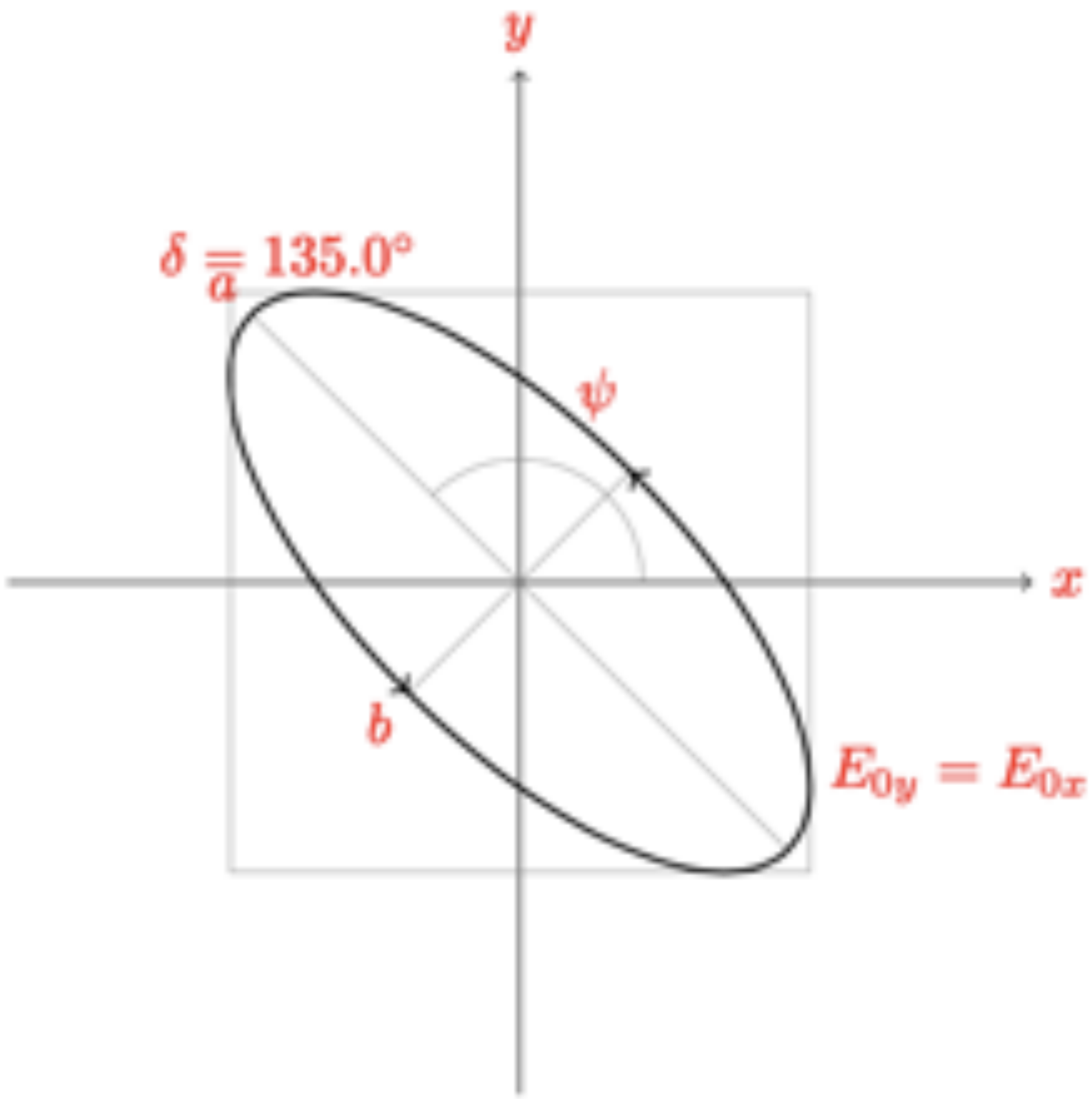
Występowanie zjawiska polaryzacji dla fali em
jest doświadczalnym dowodem na to,
że fala elektromagnetyczna jest falą poprzeczną.

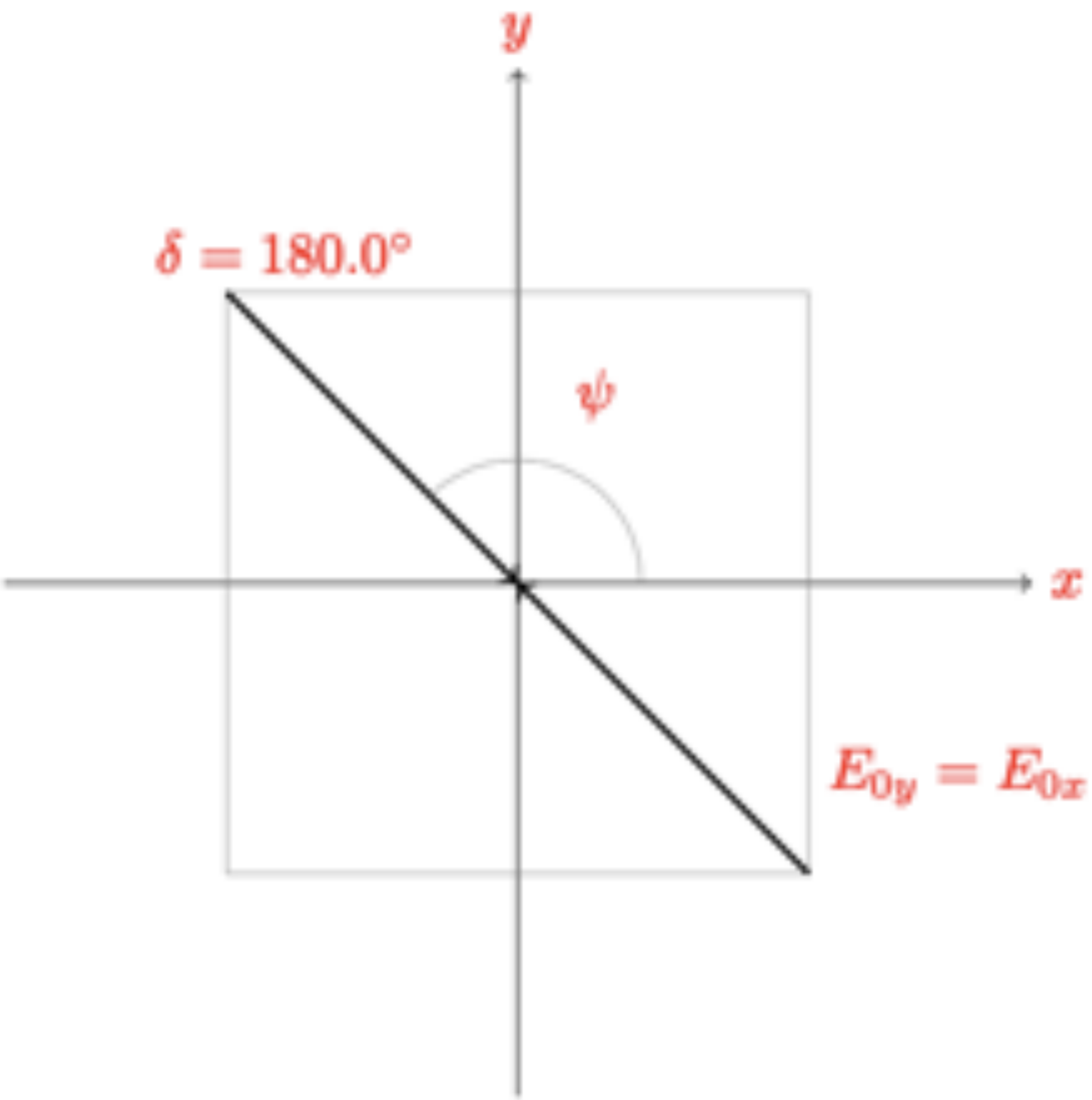


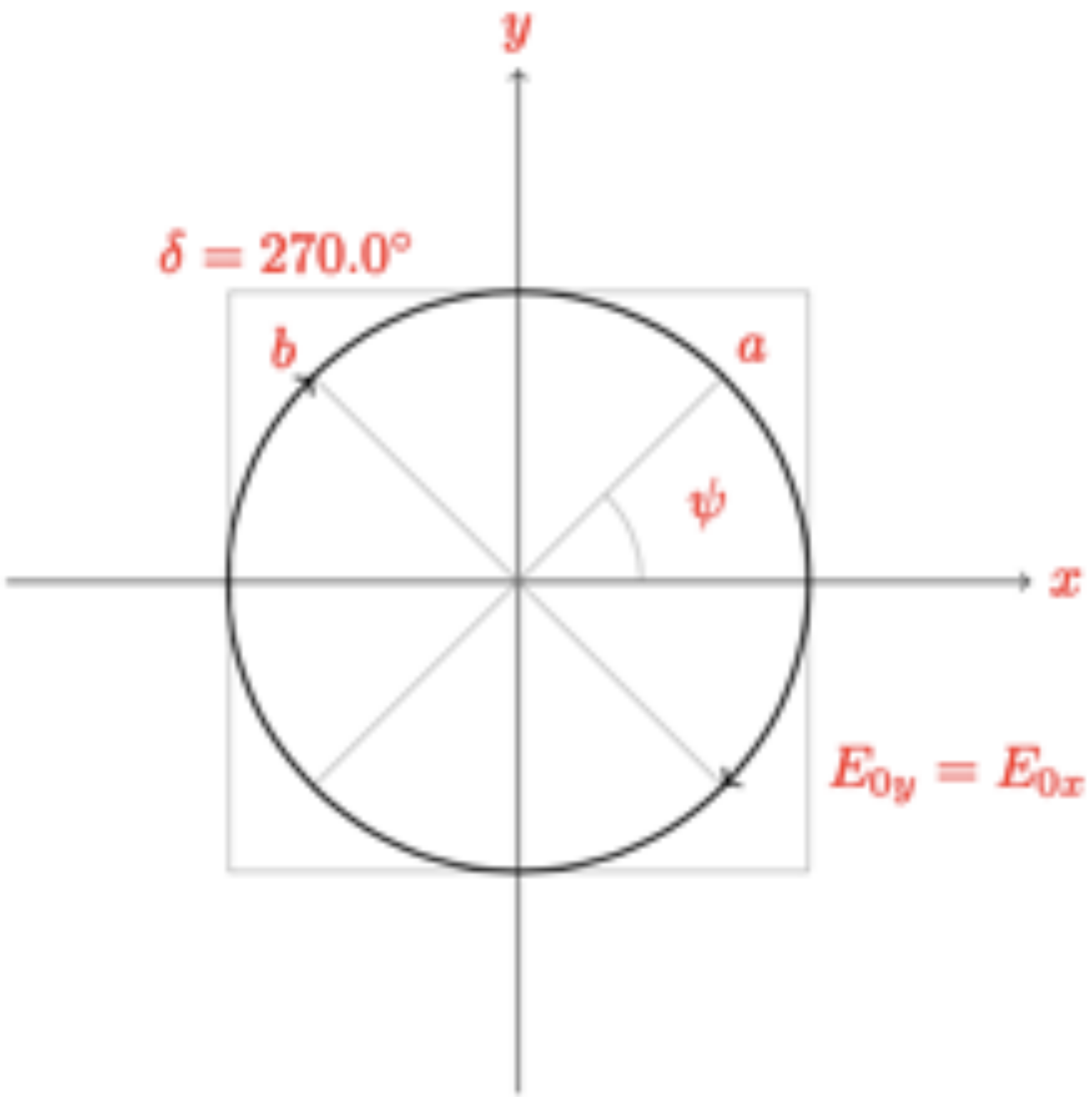

y
$\delta = 0.0°$
ψ
x
$E_{0y} = E_{0x}$


y
$\delta = 45.0°$
a
b
ψ
x
$E_{0y} = E_{0x}$


y
$\delta = 90.0°$
b
a
ψ
x
$E_{0y} = E_{0x}$


y
$\delta = 135.0°$
a
ψ
x
b
$E_{0y} = E_{0x}$

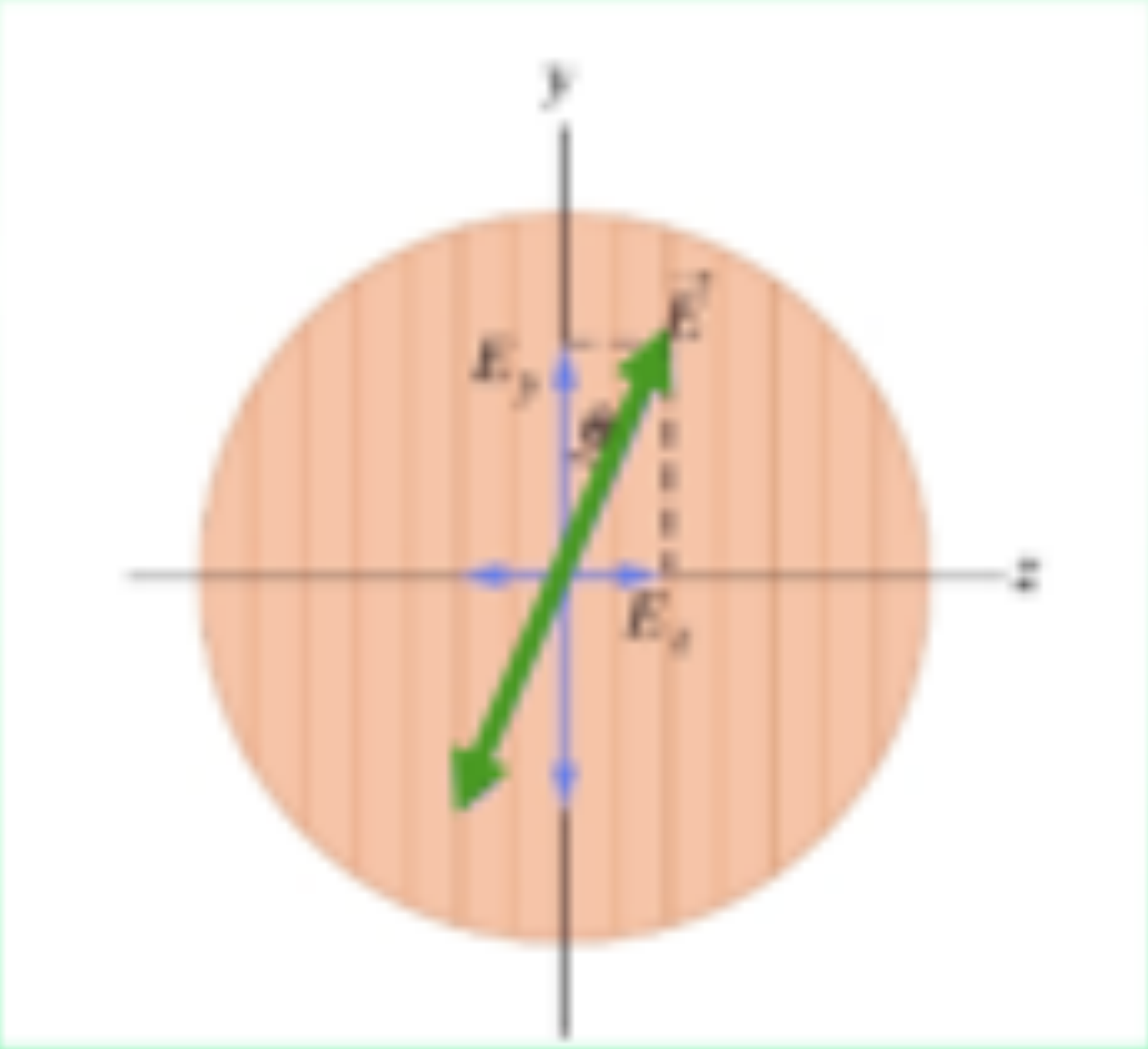

y
$\delta = 180.0°$
ψ
x
$E_{0y} = E_{0x}$


y
$\delta = 270.0°$
b
a
ψ
x
$E_{0y} = E_{0x}$

brak korelacji

pomiędzy E_y i E_z

światło niespolaryzowane



$$E_y^{\max} \neq E_z^{\max}$$

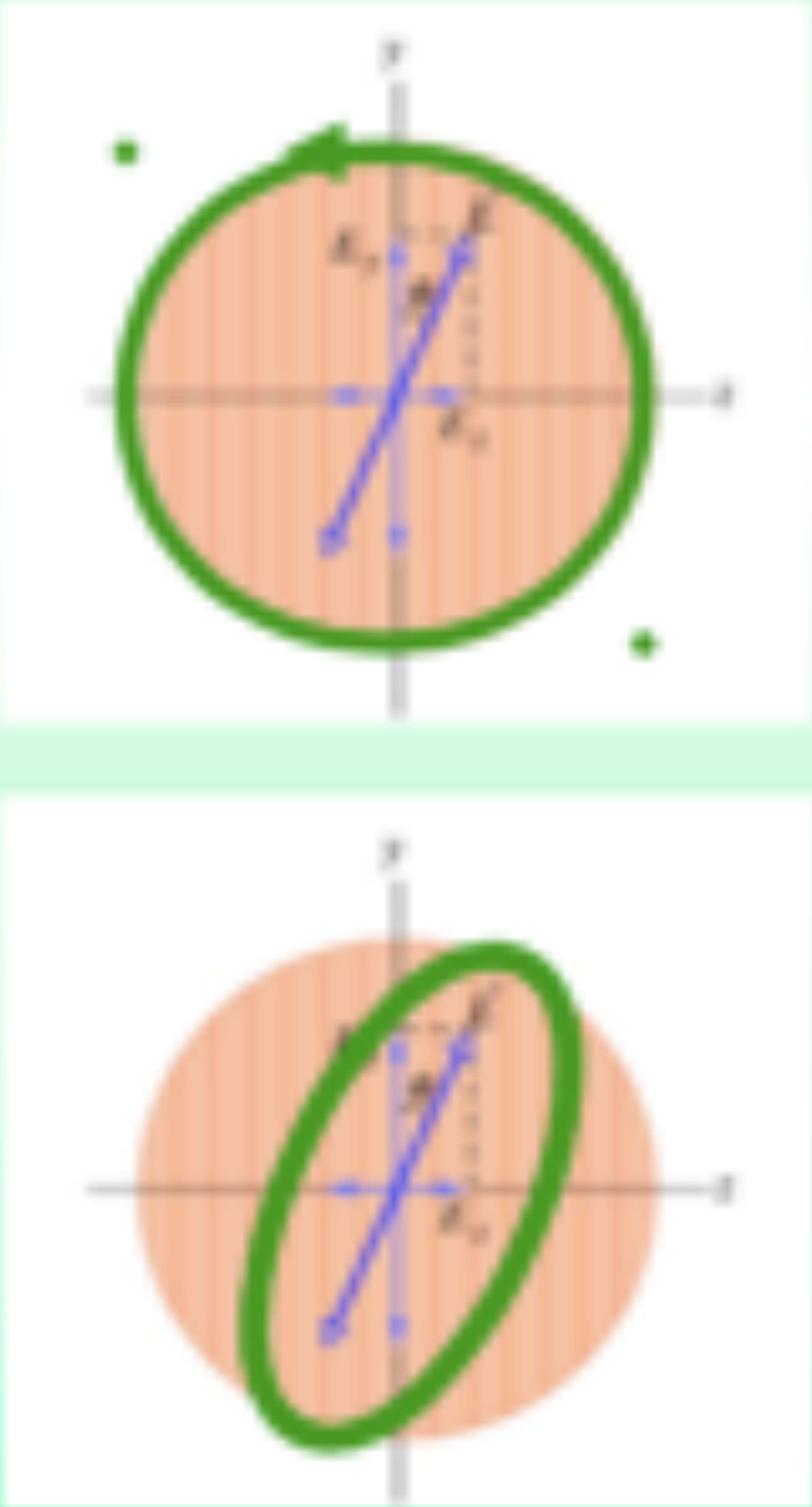
uporządkowanie

polaryzacja liniowa

$\angle\ \theta = \text{const}$

$$E_y^{\max} = E_z^{\max}$$

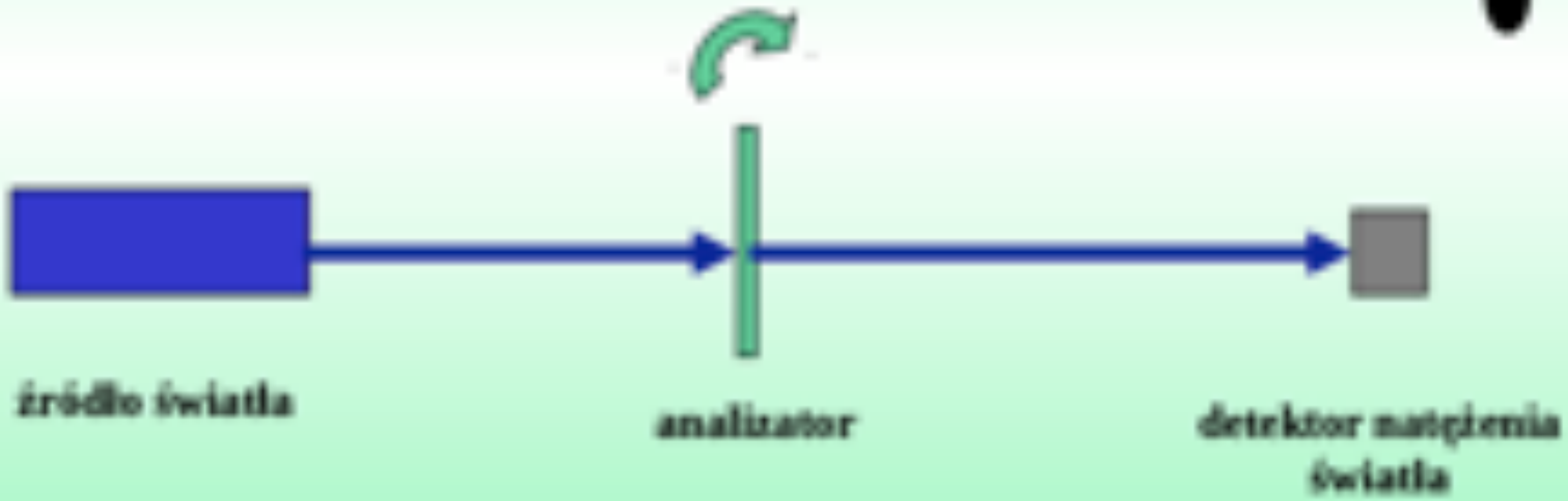
polaryzacja kołowa



Określanie stanu polaryzacji

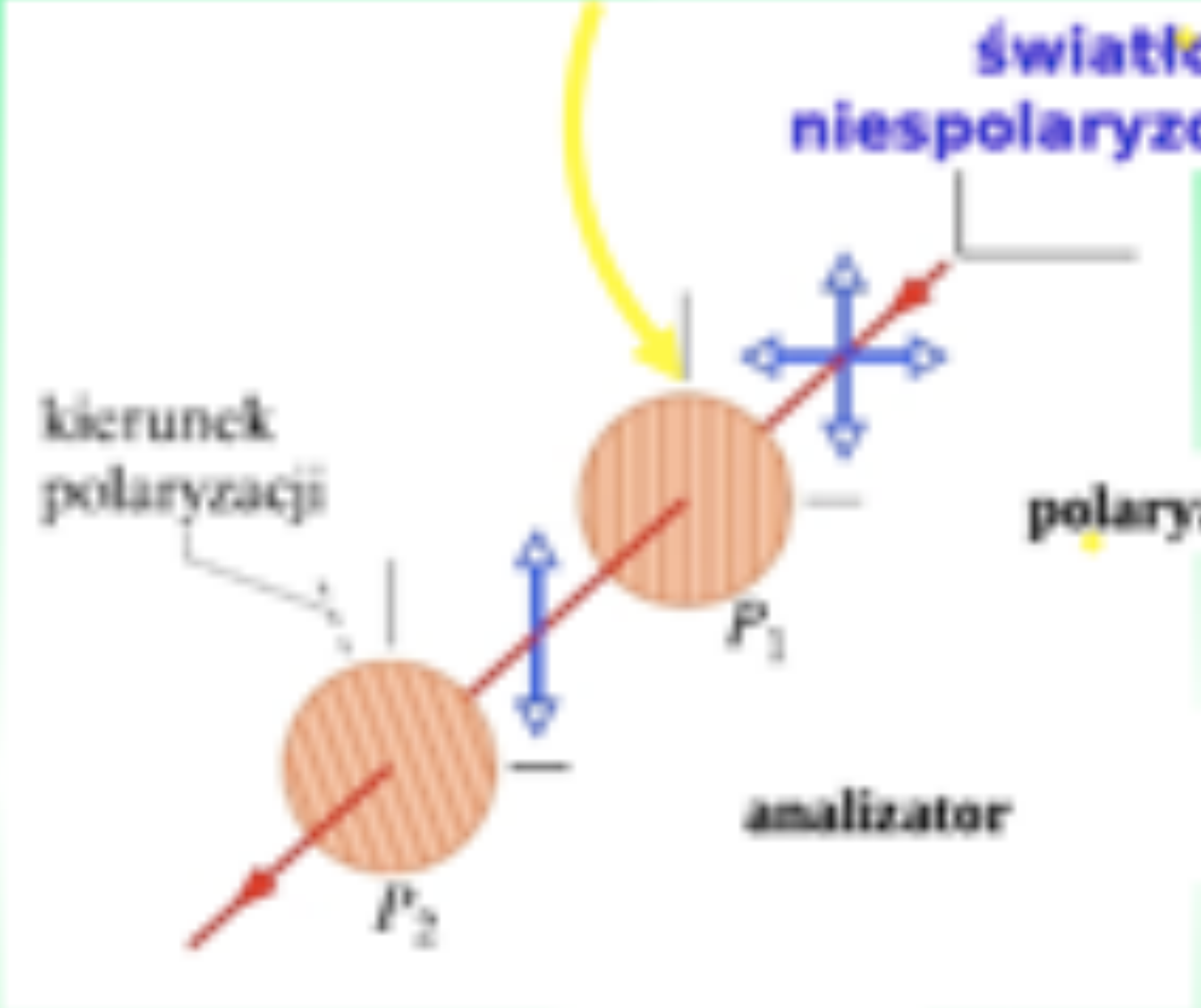
$$P = \frac{I_{\max} - I_{\min}}{I_{\max} + I_{min}}$$

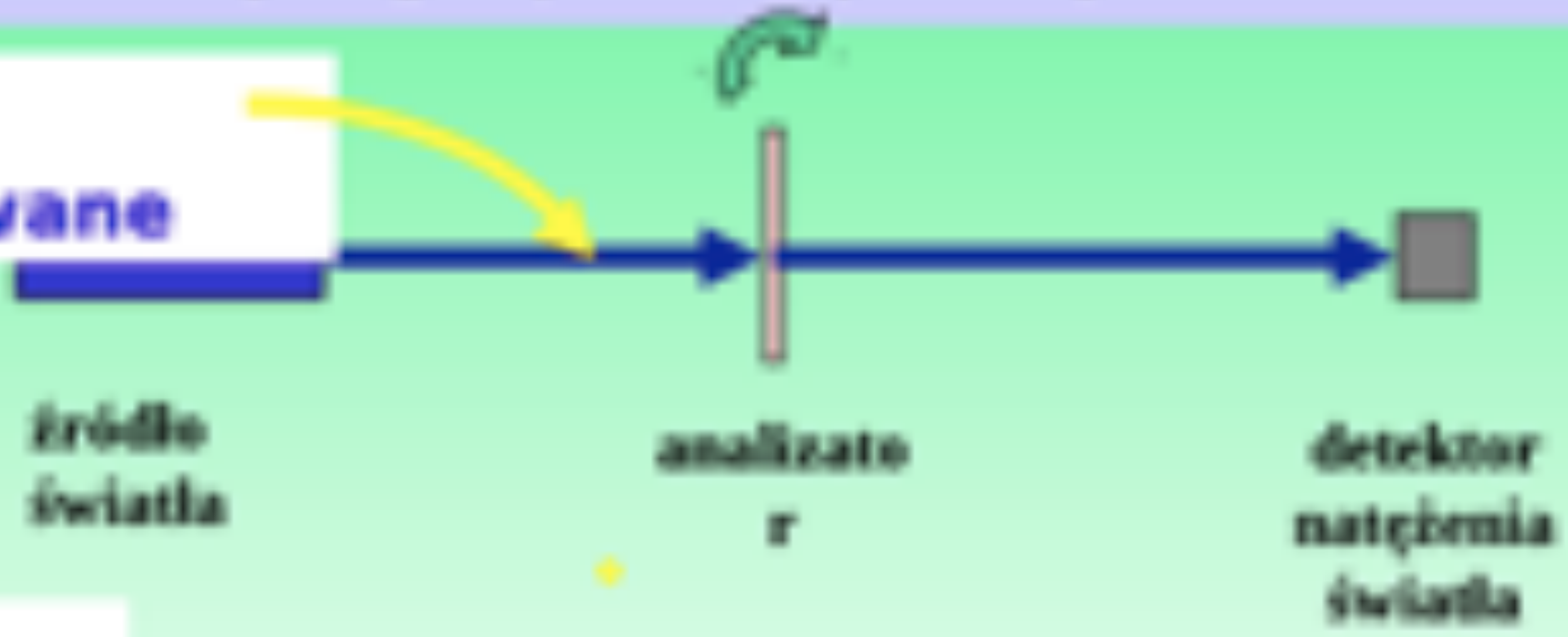
?



Natężenie światła przechodzącego przez polaryzator

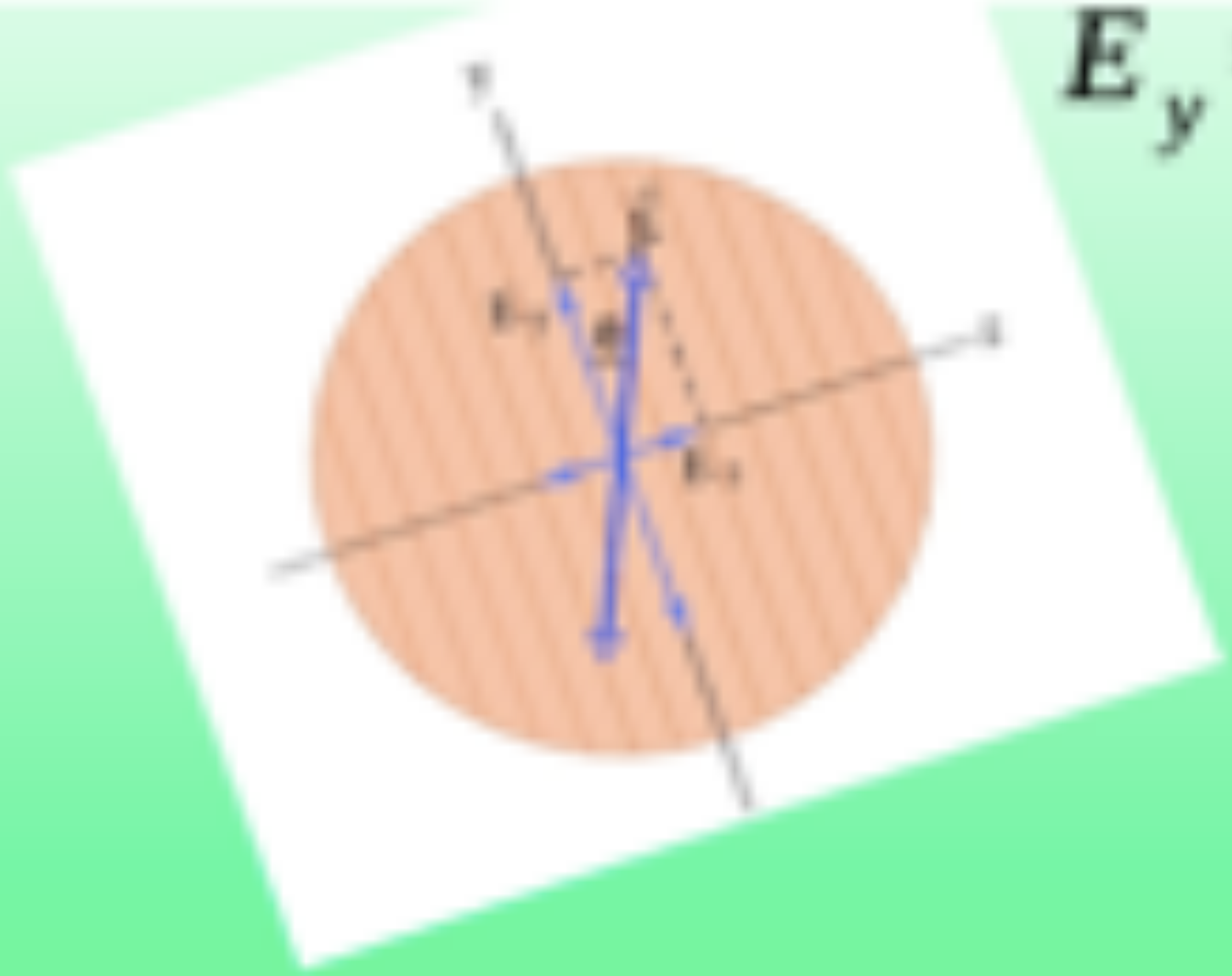
światło niespolaryzowane





$$I_{końc} = \frac{1}{2} I$$

światło liniowo spolaryzowane



$$E_y = E\cos\theta$$

$$I_y \propto E_y^2$$

$$I_{końc} = I\cos^2\theta$$

Wzory Fresnela

$$I_s^r = I_0 \left(\frac{\sin(\theta_1 - \theta_2)}{\sin(\theta_1 + \theta_2)} \right)^2 \quad I_p^r = I_0 \left(\frac{tg(\theta_1 - \theta_2)}{tg(\theta_1 + \theta_2)} \right)^2$$

$$I_s^t = I_0 \left(\frac{2 \sin\theta_1 \cos\theta_2}{\sin(\theta_1 + \theta_2)} \right)^2 \quad I_p^t = I_0 \left(\frac{2 \sin\theta_1 \cos\theta_2}{\sin(\theta_1 + \theta_2) \sin(\theta_1 - \theta_2)} \right)^2$$

r – odbicie

t – załamanie

I_0 – natężenie światła padającego

s - polaryzacja wiązki prostopadła do płaszczyzny padania

p - polaryzacja wiązki równoległa do płaszczyzny padania

θ_1 – kąt padania

θ_2 – kąt załamania

Kąt Brewstera

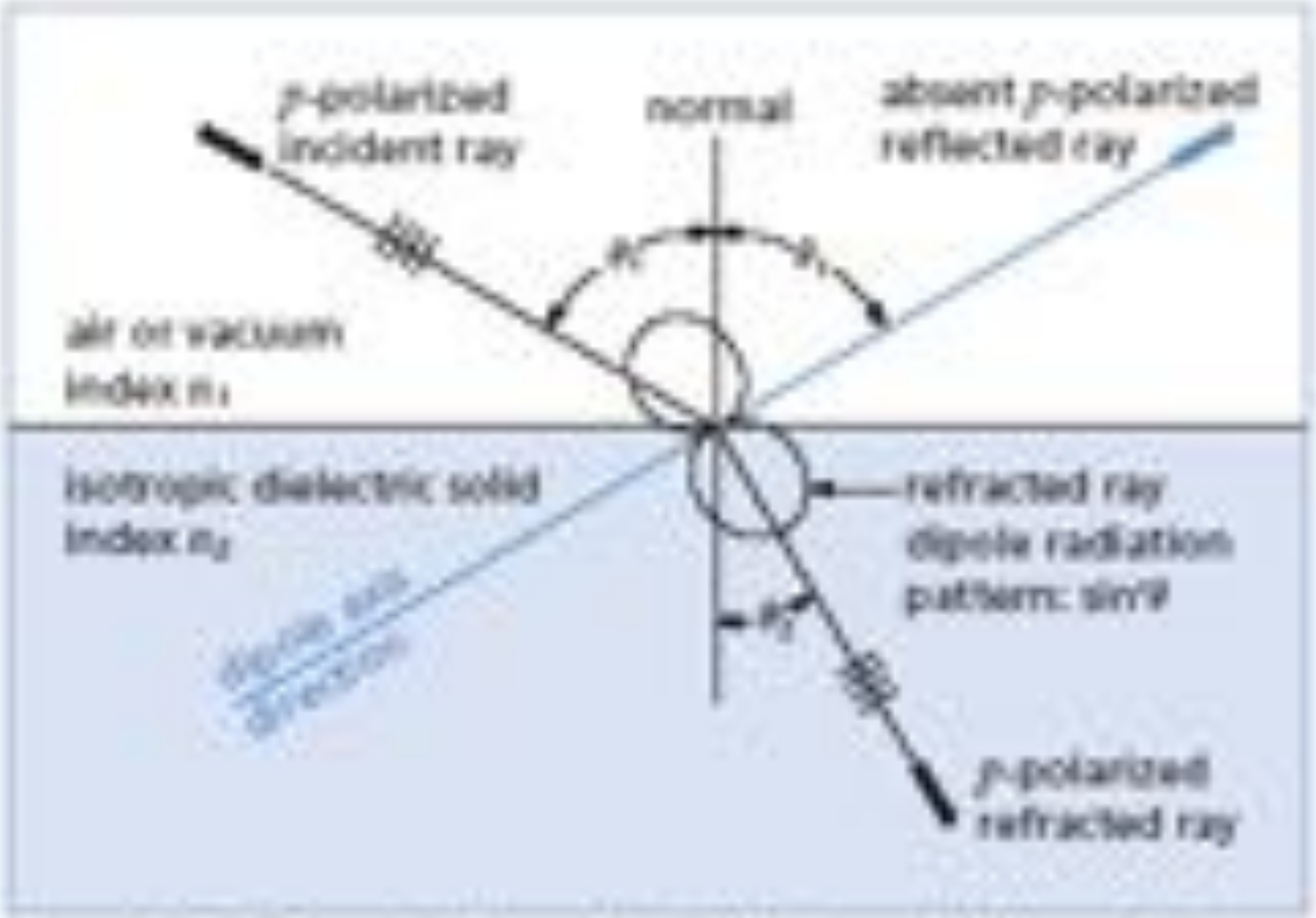


Figure 5.3 Brewster's angle: at this angle, the p-polarized component is completely absent in the reflected ray

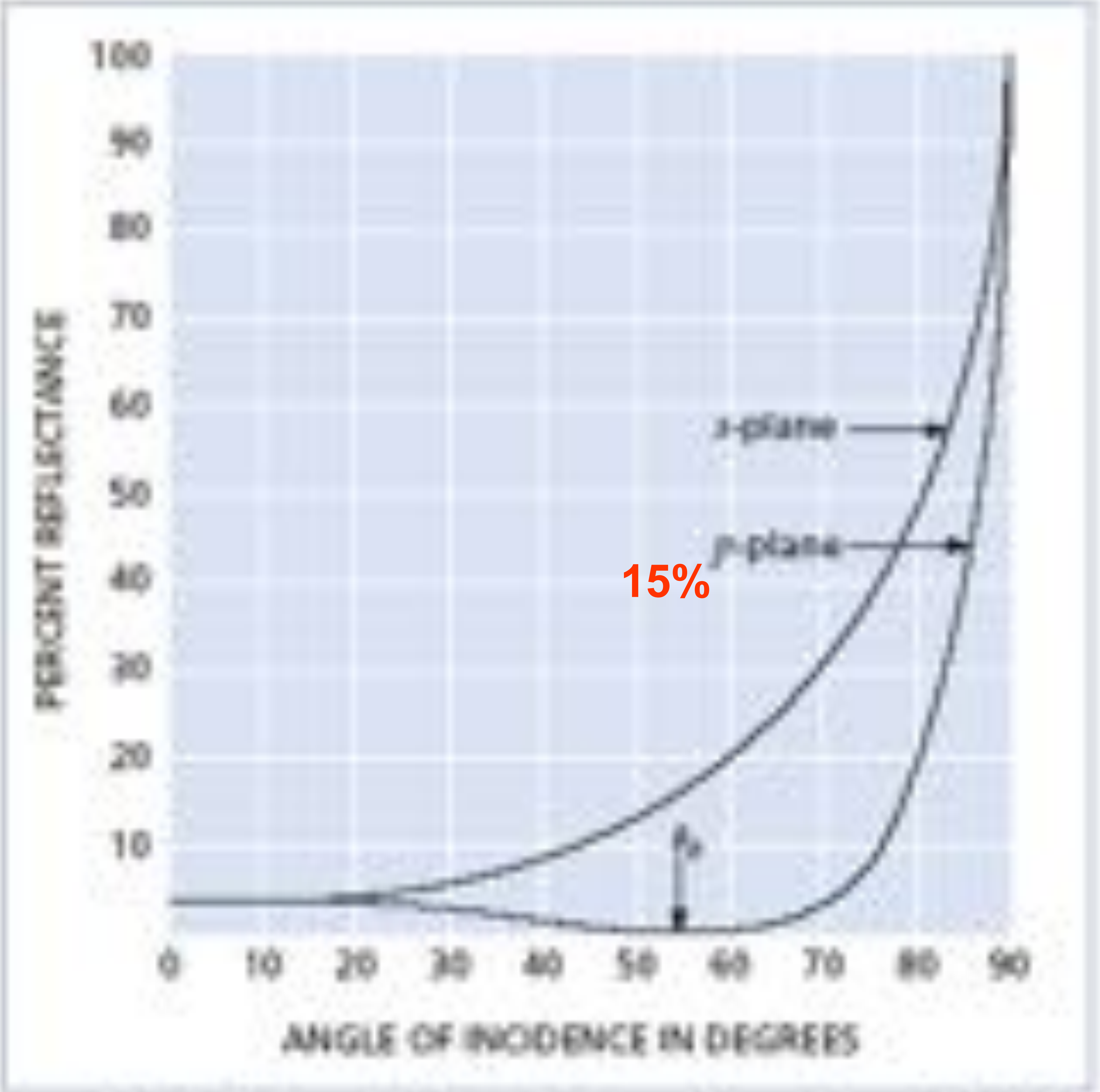


Figure 5.2 External reflection at a glass surface ($n = 1.52$) showing s- and p-polarized components

Odbicie na granicy dwóch ośrodków dielektrycznych

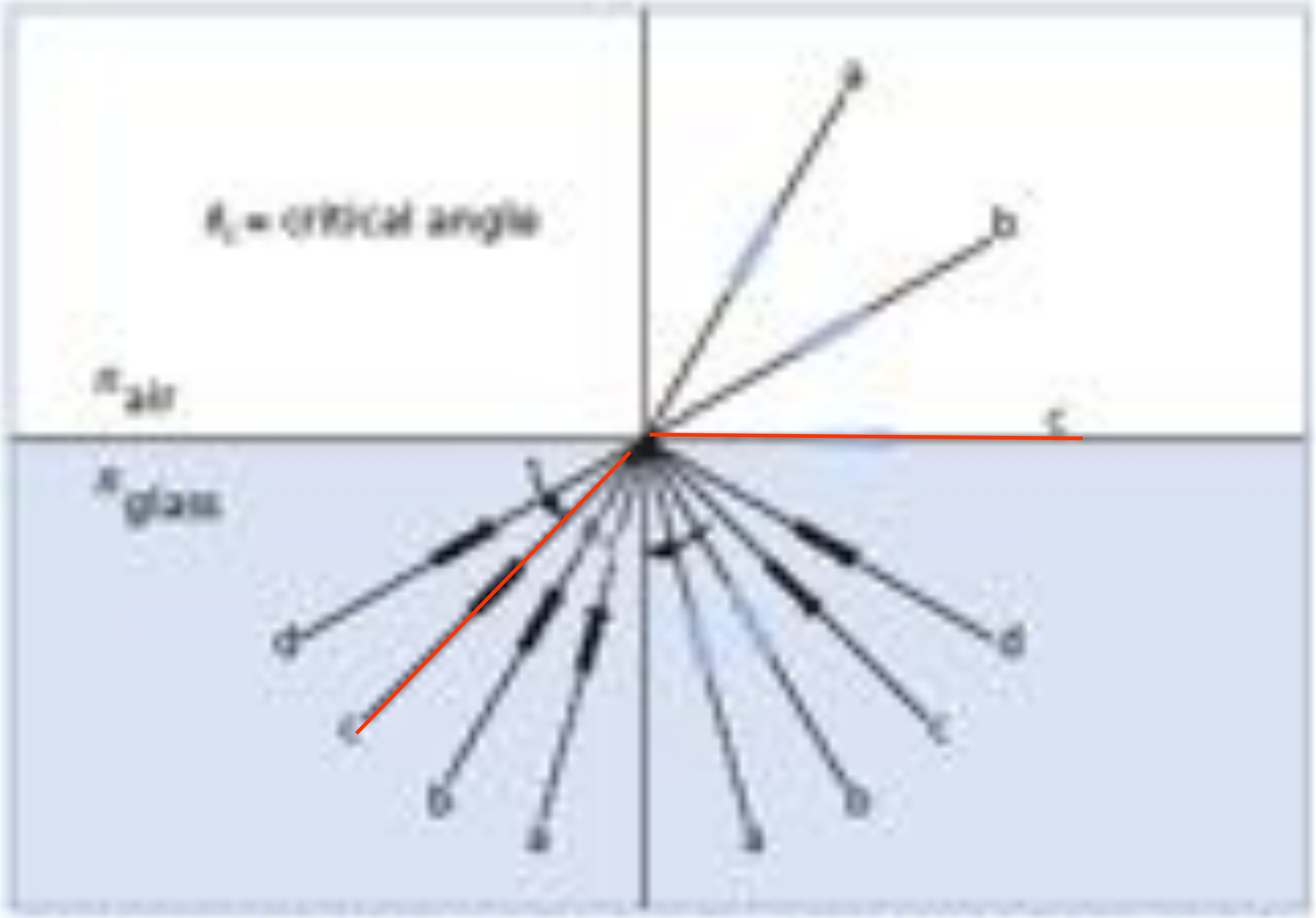


Figure 5.4 Internal reflection at a glass surface (n = 1.52) showing s- and p-polarized components

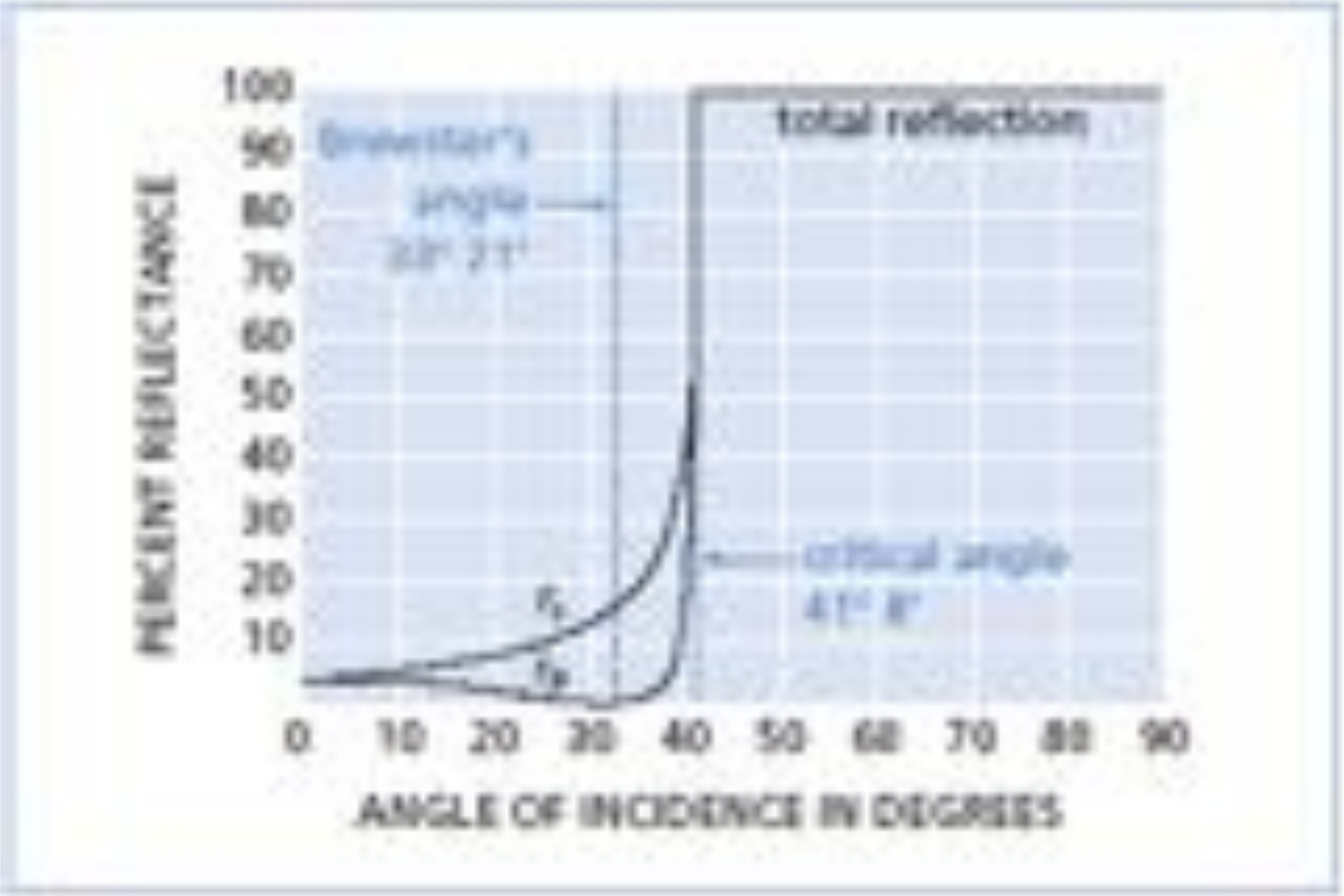


Figure 5.5 Critical angle: at this angle, the emerging ray is at grazing incidence

$$\theta_c(\lambda) = \arcsin\left(\frac{1}{n(\lambda)}\right)$$

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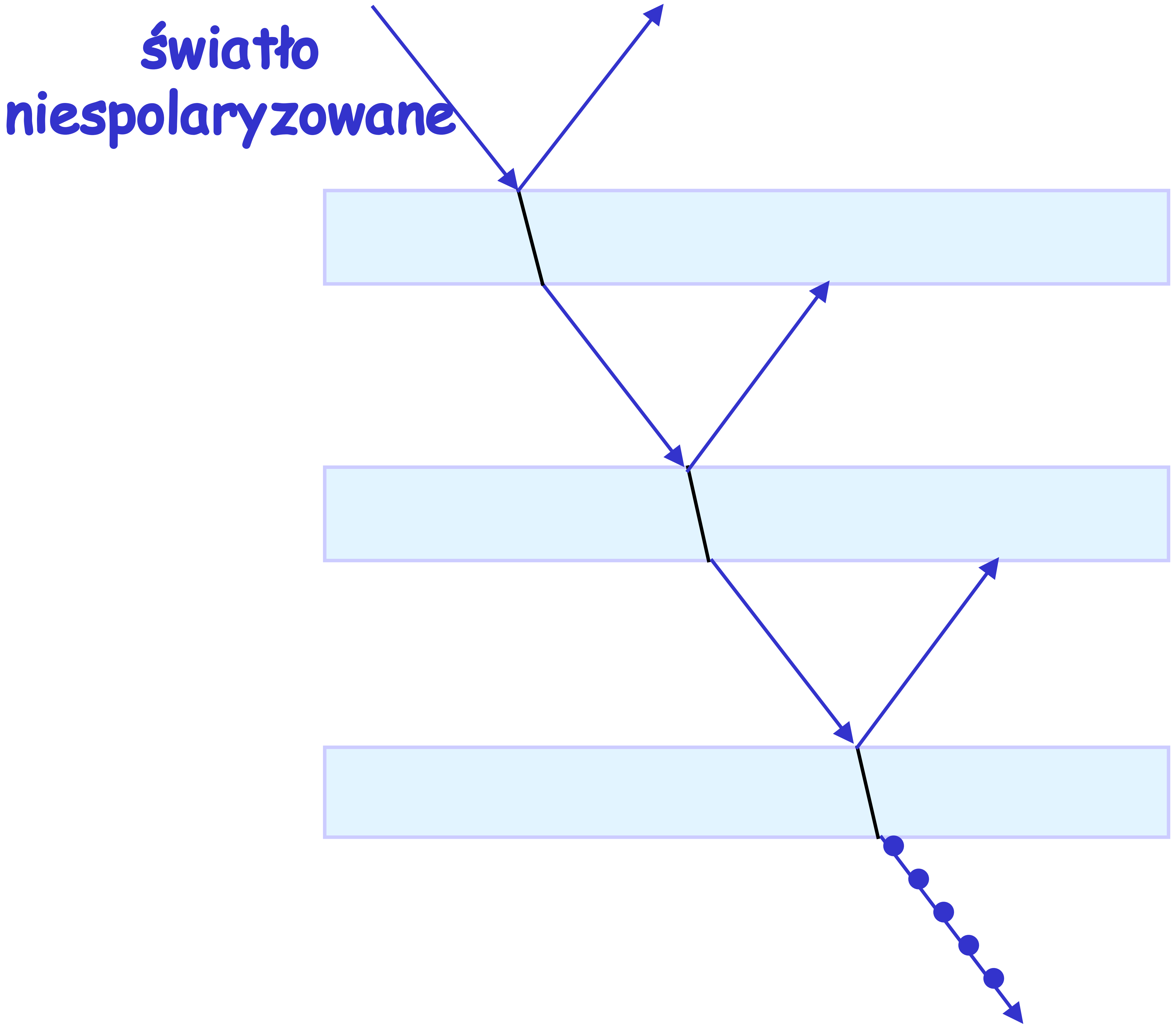
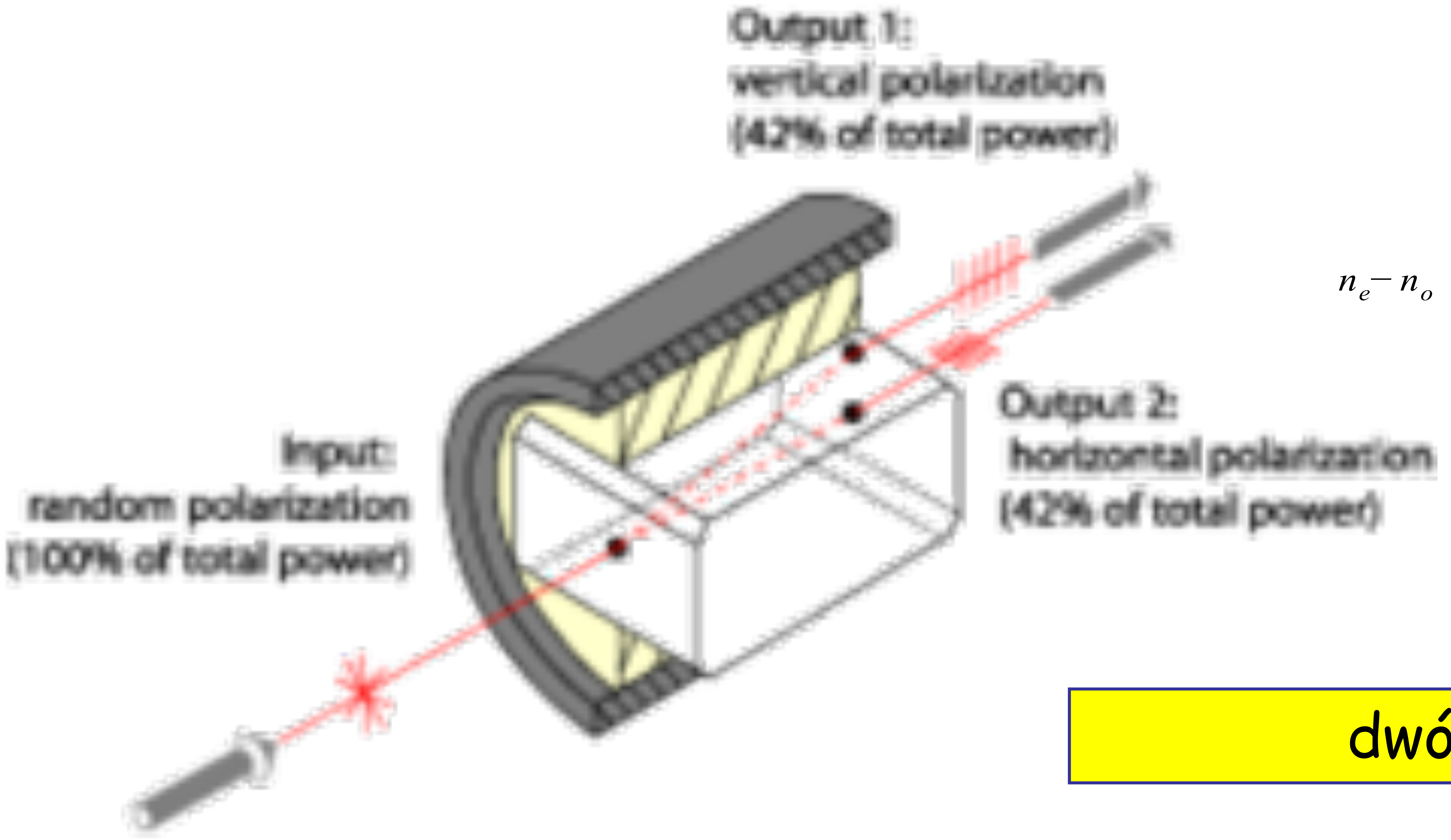
Polaryzacja światła przez załamanie



ilość płytek	stopień polaryzacji %
1	8
10	67
20	80
45	90

stos szklany – polaryzator płytkowy

Polaryzacja światła przez podwójne załamanie



$n_e - n_o$

dwójłomność

Wiązki wychodzące są liniowo spolaryzowane, prostopadle do siebie.

Biegną równolegle do siebie.

Odległość między nimi zależy od długości fali i długości pryzmatu.

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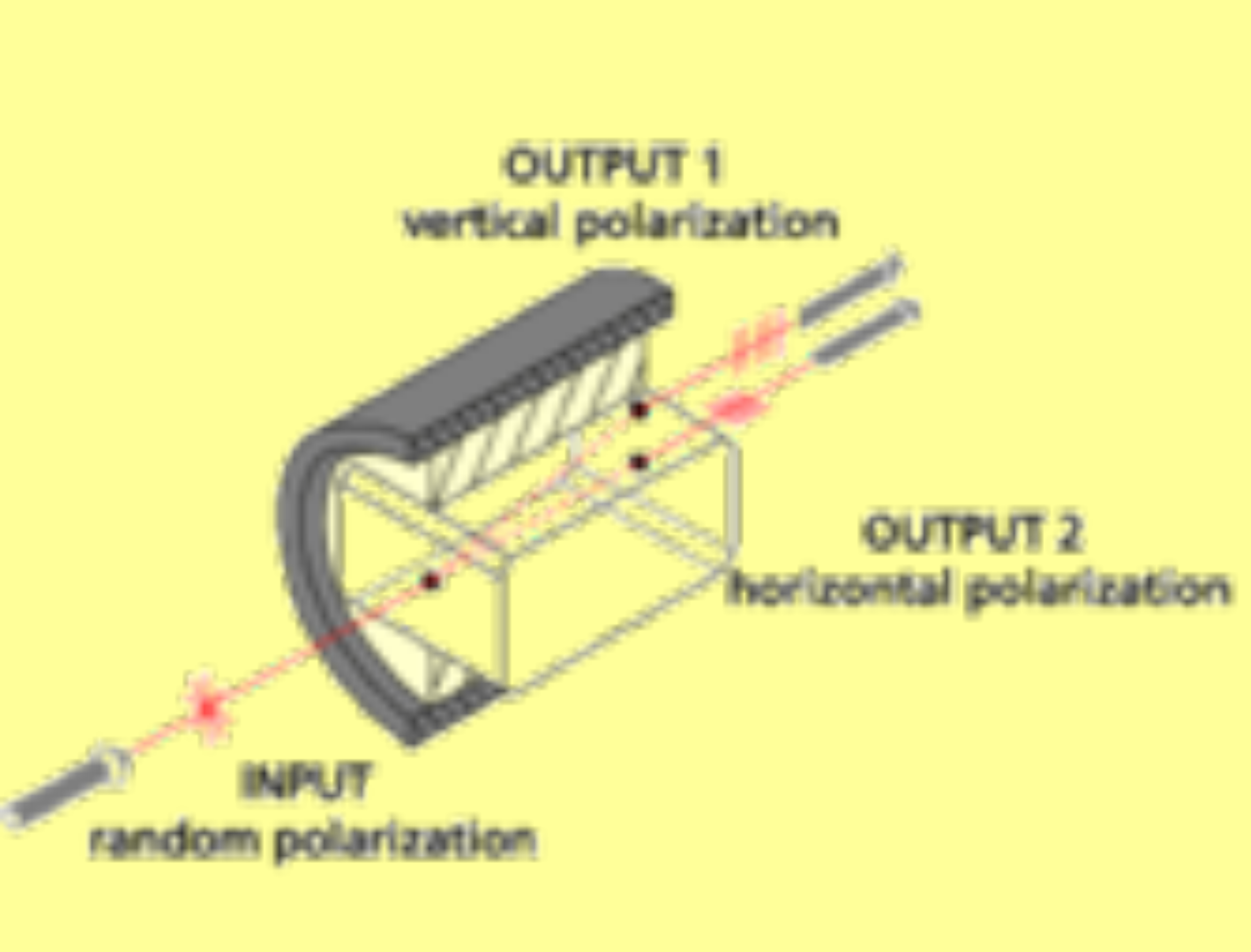
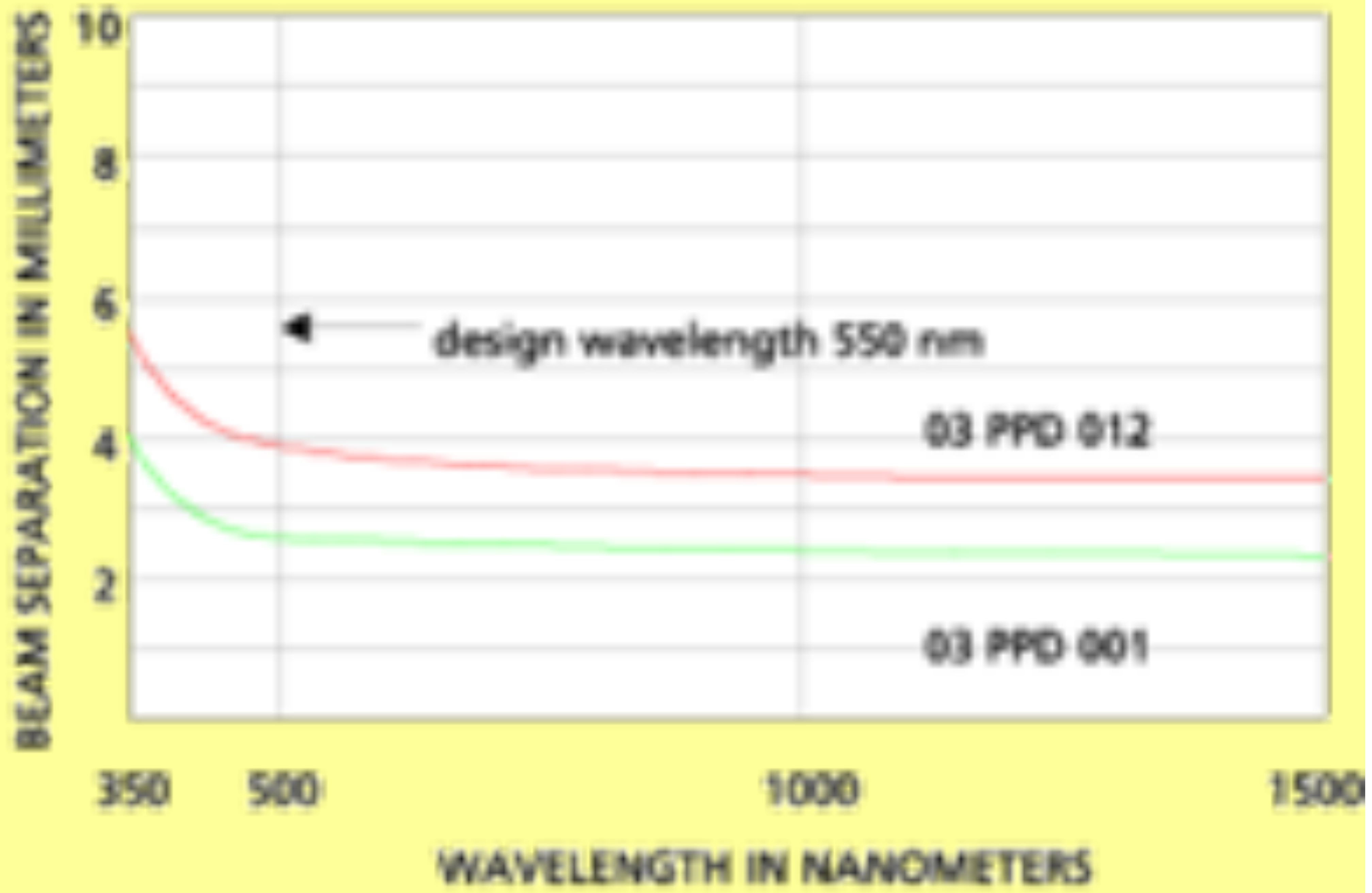
Pryzmaty polaryzacyjne





beam displacing prism

Wiązki wychodzące są liniowo spolaryzowane, prostopadle do siebie.

Biegną równolegle do siebie.

Odległość między nimi od długości fali i długości pryzmatu.

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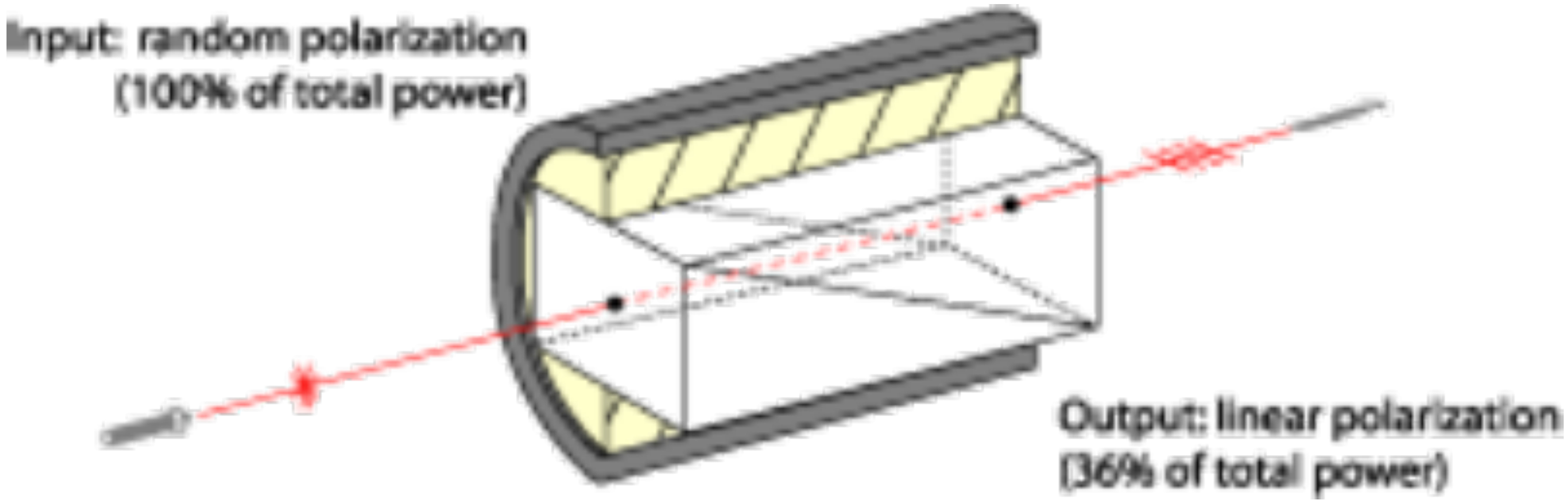
Pryzmaty polaryzacyjne



Glan – Thomson prism

Wiązka wychodząca jest liniowo spolaryzowana i nie jest odchylona.

Pozostała część wiązki jest absorbowana przez obudowę pryzmatu.

Szersze pole widzenia.

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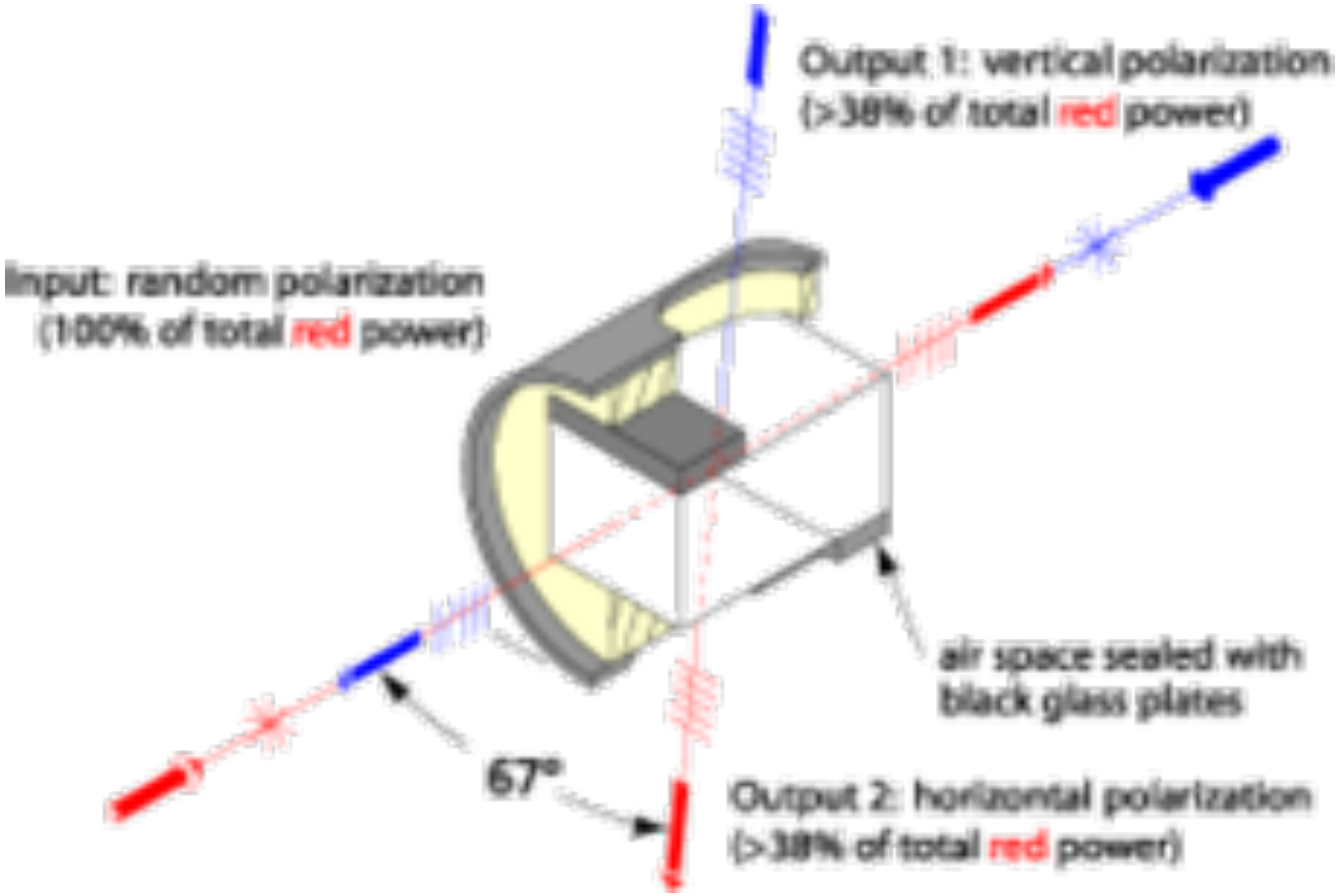
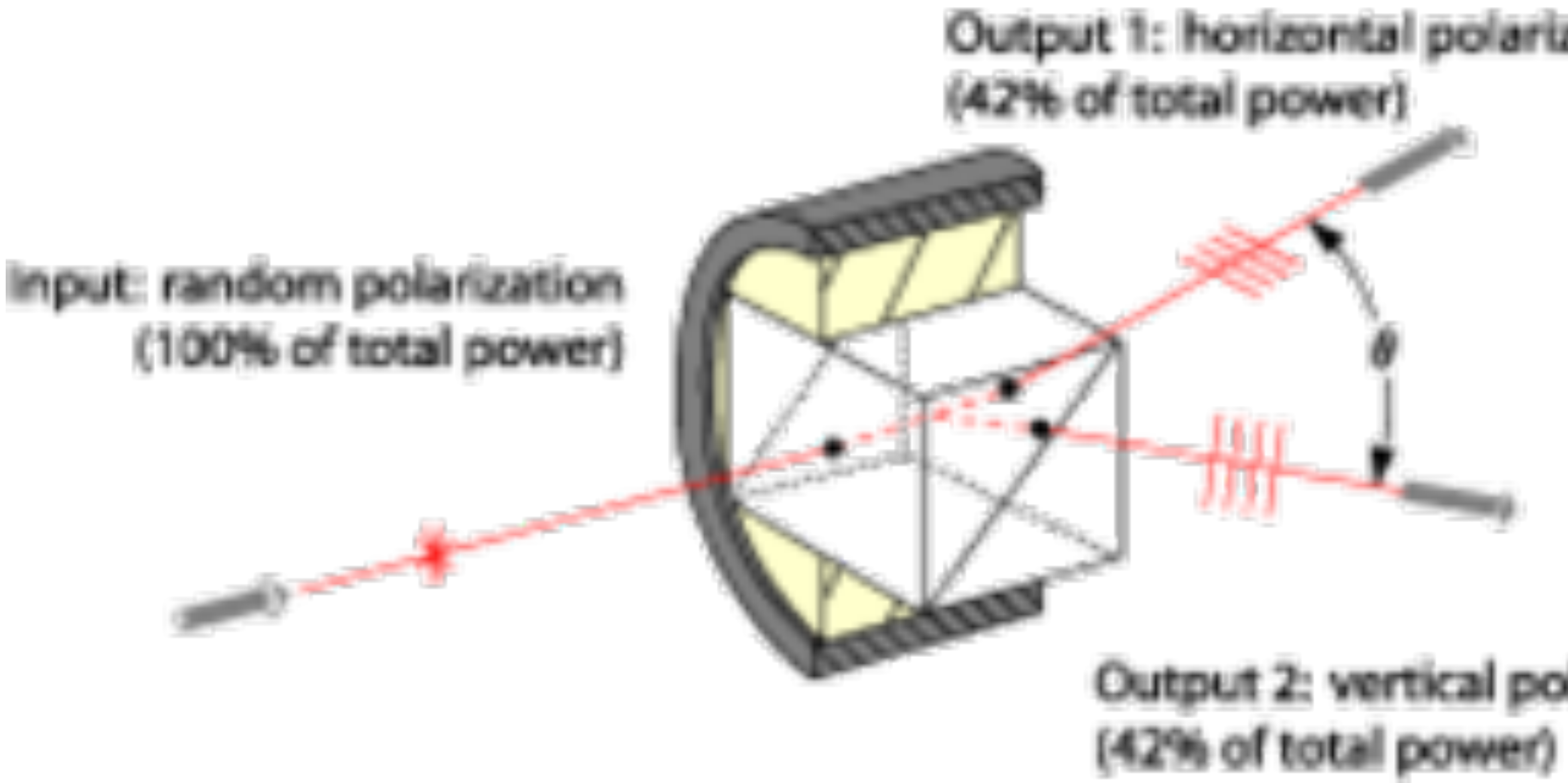
Pryzmat polaryzacyjny Glana-Thomsona



Wiązka wychodząca jest liniowo spolaryzowana i nie jest odchylona.
Pozostała część wiązki wydostaje się poza obudowę pryzmatu pod kątem 67°.
Umożliwia to pracę z wiązką o stosunkowo dużej energii.

http://www.mellesgriot.com

Pryzmat polaryzacyjny Wollastona



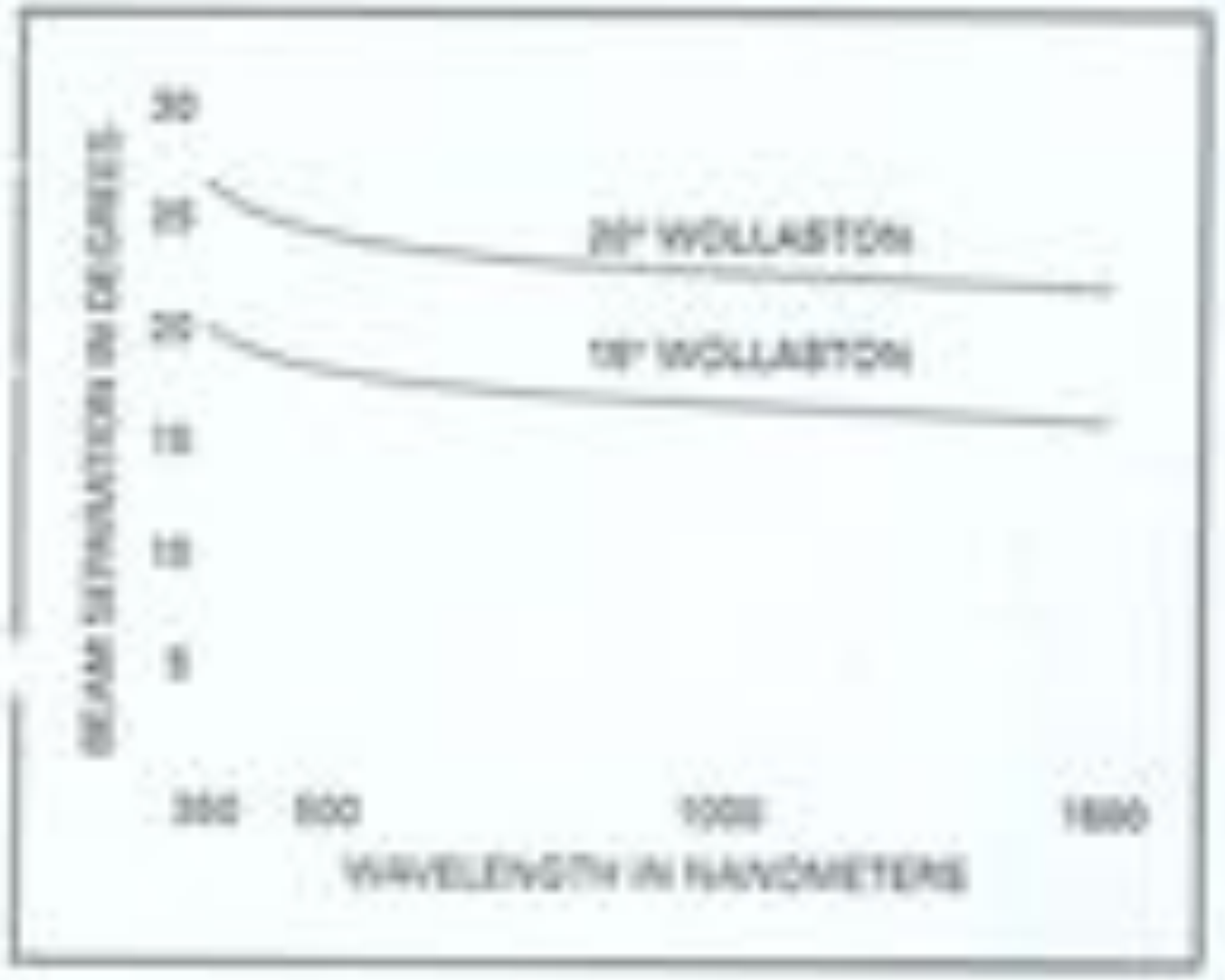
Wiązki wychodzące są liniowo spolaryzowane, prostopadle do siebie.
Kąt Θ zależy od długości fali i długości pryzmatu.
Każda z wiązek jest odchylona o połowę kąta Θ.
Kąt Θ specyfikuje się na 15° lub 20°.

http://www.mellesgriot.com

Melles Griot Wollaston prisms provide a simple and convenient way to split a beam of light into two mutually orthogonal linearly polarized beams. Two angular separation versions and three quality grades are available. After passing through the prism, the beams diverge from one another by an angle of approximately 15° or 20°.

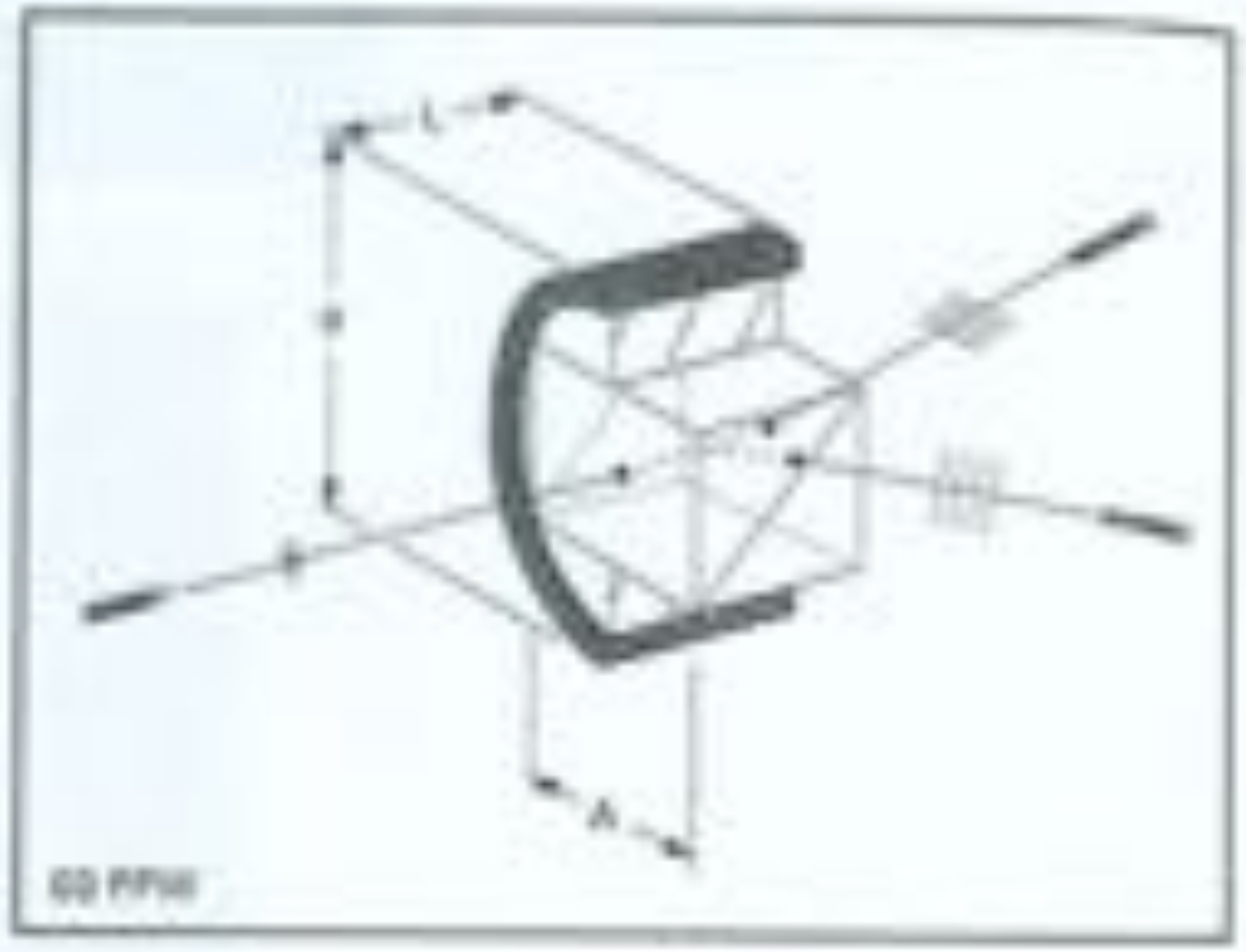
Wollaston prisms provide a convenient method of providing double images of single sources, such as the Young two-slit experiment and scatter plate interferometry.

Beam separation angle between the orthogonally plane polarized output is wavelength dependent. Each beam is deviated approximately half of the divergence from the input beam. There is some asymmetry of the deviation between the two beams. The specific separation angle (for both separation values), as a function of wavelength, is best seen by inspecting the graph below. The two halves of these prisms are cemented together. Useful transmission is from 350 nm to 2300 nm.



Single layer, magnesium fluoride, antireflection coatings are available for these prisms. These coatings, which are effective over a broad range of wavelengths, are centered at 550 nm for visible range use or at 830 nm for near-infrared range applications.

Melles Griot Wollaston prisms are mounted in a black anodized cylindrical aluminum housing. The component's Product Number



is permanently engraved on the side. This housing mounts easily and conveniently in adapters for the Melles Griot polarizer holder *(see Chapter 21, Optical Component Holders)*. The Wollaston prism is held within the mount by a black polymeric material.

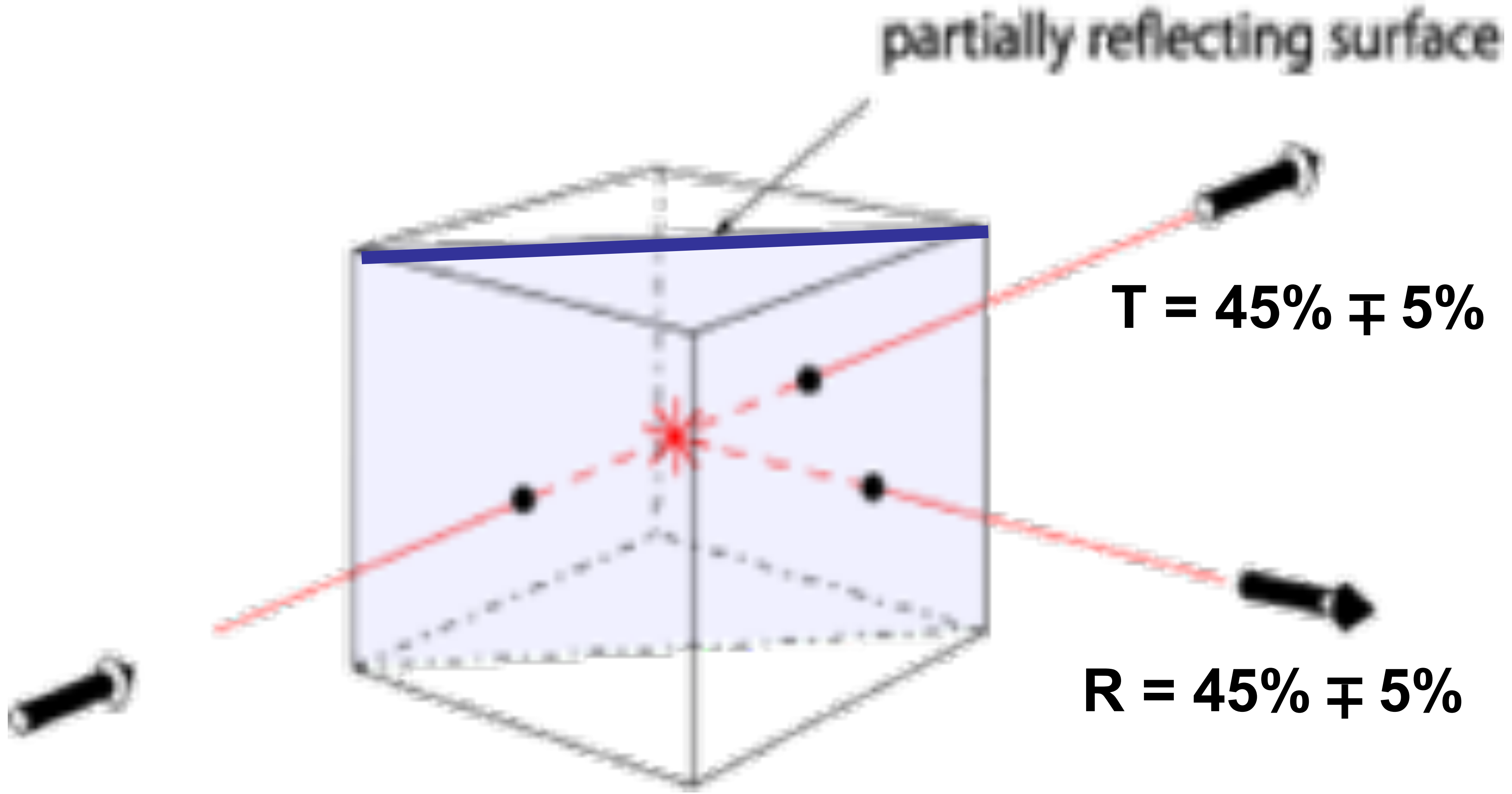
kordieryt – glinokrzemian magnezu $Mg_2Al_3(alSi_5O_{18})$

„Kompas zmierzchu” umożliwia określenie położenia słońca po jego zachodzie z dokładnością nawet do 2,5° mimo, że znajduje się ono 7° poniżej linii widnokręgu.
Prawdopodobnie był to kompas Wikingów, podróżujących na dużych szerokościach geograficznych.

Wykorzystuje się tu zmiany polaryzacji nieba
wraz ze zmianą kierunku obserwacji w stosunku do słońca.

http://www.wikipedia.org

Elementy światłodzielące



warstwa metaliczna

Zalety w stosunku do płytek światłodzielących:
- **+ łatwiejsze do mocowania,**
- **+ mniejszy wpływ naprężeń mechanicznych na deformację,**
- **+ mniej wiązek błądzących,**
- **+ mniejsza degradacja w czasie powierzchni częściowo odbijającej.**

Uwaga: Czarna kropka na spodzie pryzmatu wskazuje, że na podstawie tego pryzmatu naniesiono warstwę częściowo odbijającą i światło powinno wpierw padać na powierzchnie boczną tego pryzmatu.

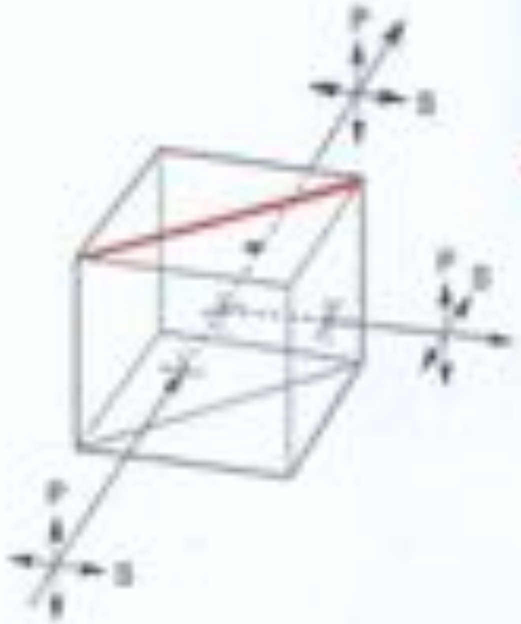
http://www.mellesgriot.com

Specifications

SZEROKOPASMOWY PRYZMAT DZIELĄCY

Material	BK 7, grade A, fine annealed optical glass
Surface Flatness	≤ λ/4 at 632.8 nm over the clear aperture
Clear Aperture	Central diameter > 80% of dimension
Surface Quality	40-20 scratch-dig
Transmission	45 ± 5%, independent of polarization
Reflection	45 ± 5%, independent of polarization
Polarization	S- and P-polarization components matched to within 10%
Absorption	< 10%
Transmitted Beam Deviation	≤ 5 arc min
Reflected Beam Deviation	90° ± 5 arc min
Angle of Incidence	0° ± 5°
Dimensions	± 0.25 mm
Antireflection Coating	Broadband, multilayer coating, R < 0.5% per surface
Temperature Range	–50°C to +90°C
Durability	MIL-M-13508, MIL-C-675, MIL-C-14806
[illegible]entation	To avoid damage, beam should enter prism marked with a dot
Cleaning	Non-abrasive method, acetone or isopropyl alcohol on lens tissue recommended Cemented optic, do not immerse in a solvent
Damage Threshold	100 W/cm² CW, 0.1 J/cm² with 10 nsec pulses

Note: For information on laser damage threshold see page 13-16.



WARSTWA METALICZNA

Ordering Information

Wavelength Range (nm)	Dimensions (mm)	Product Number
400–700	12.7	05BC17MB.1
400–700	25.4	10BC17MB.1
400–700	50.8	20BC17MB.1
700–1100	12.7	05BC17MB.2
700–1100	25.4	10BC17MB.2
700–1100	50.8	20BC17MB.2

ULTIMA Series Precision Mounts

CH Series Cell Holders

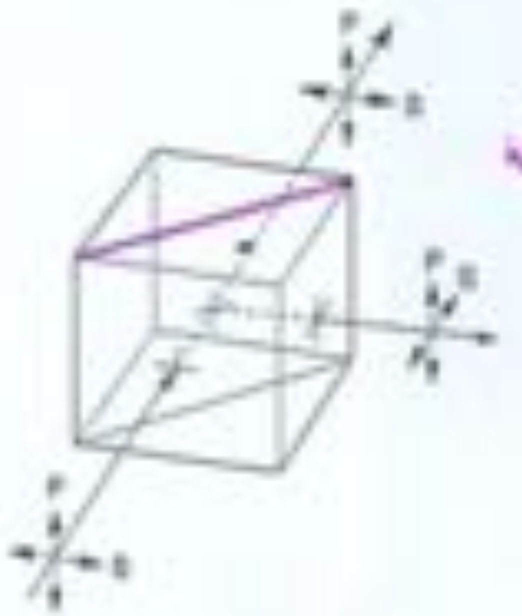
PO Series Tilt/Rotation Stage

Laser Line Non-Polarizing Cube Beamsplitters

Specifications

Material	BK 7, grade A, fine annealed optical glass
Wavefront Distortion	≤ λ/4 at 632.8 nm over the clear aperture
Clear Aperture	Central diameter, > 80% of dimension
Surface Quality	20-10 scratch-dig
Transmission	50 ± 3%, independent of polarization
Reflection	50 ± 3%, independent of polarization
Polarization	S- and P-polarization components matched to within 3%
Transmitted Beam Deviation	≤ 5 arc min
Reflected Beam Deviation	90° ± 15 arc min
Angle of Incidence	0° ± 2°
Dimensions	± 0.25 mm
Antireflection Coating	Multilayer coating, R < 0.5% per surface
Temperature Range	−50°C to +90°C
Durability	MIL-M-13508, MIL-C-675, MIL-C-14806
Orientation	To avoid damage, beam should enter prism marked with a dot
Cleaning	Non-abrasive method, acetone or isopropyl alcohol on lens tissue recommended Cemented optic, do not immerse in a solvent
Damage Threshold	2 kW/cm² CW, 1 J/cm² with 10 nsec pulses

Note: For information on laser damage threshold see page 12-56.



NIEPOLARYZUJĄCA
KOSTKA
DIELEKTRYCZNA

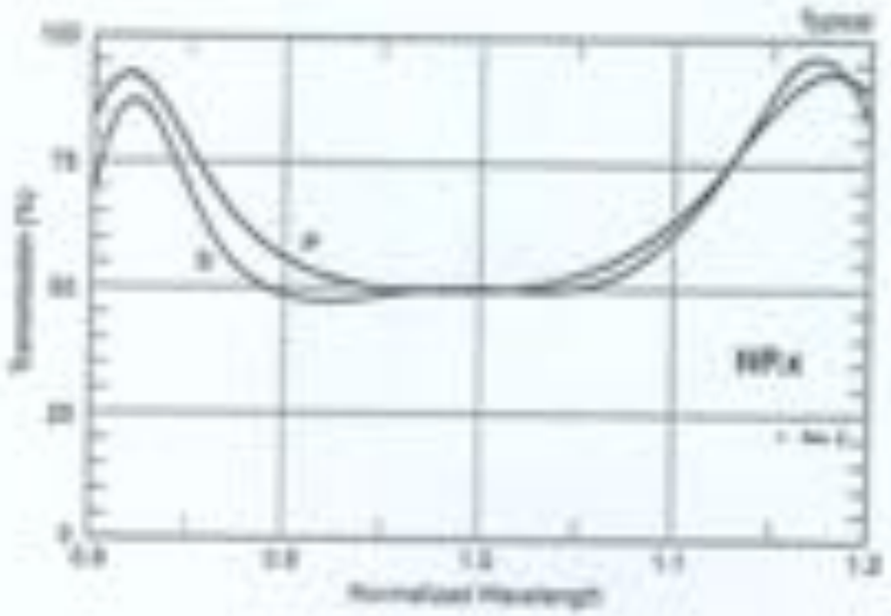
Related Products

- PERFORMA Series Optical Mounts
- ULTIMA Series Precision Mounts
- 488 Rotary Platform
- PO Series Tilt/Rotation Stages
- PT-1 Prism Table
- CH Series Cube Holders

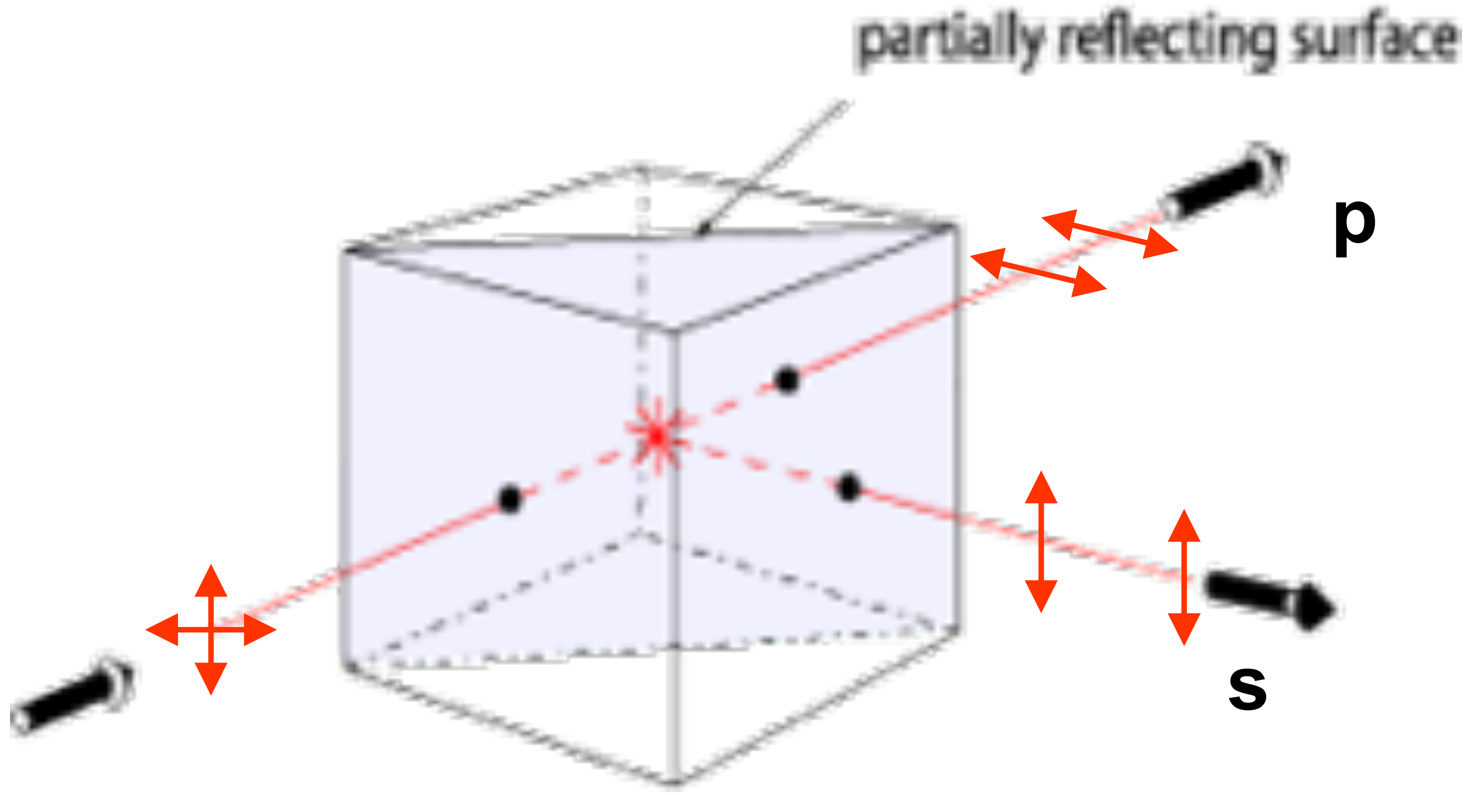
PERFORMA Series Optical Mounts

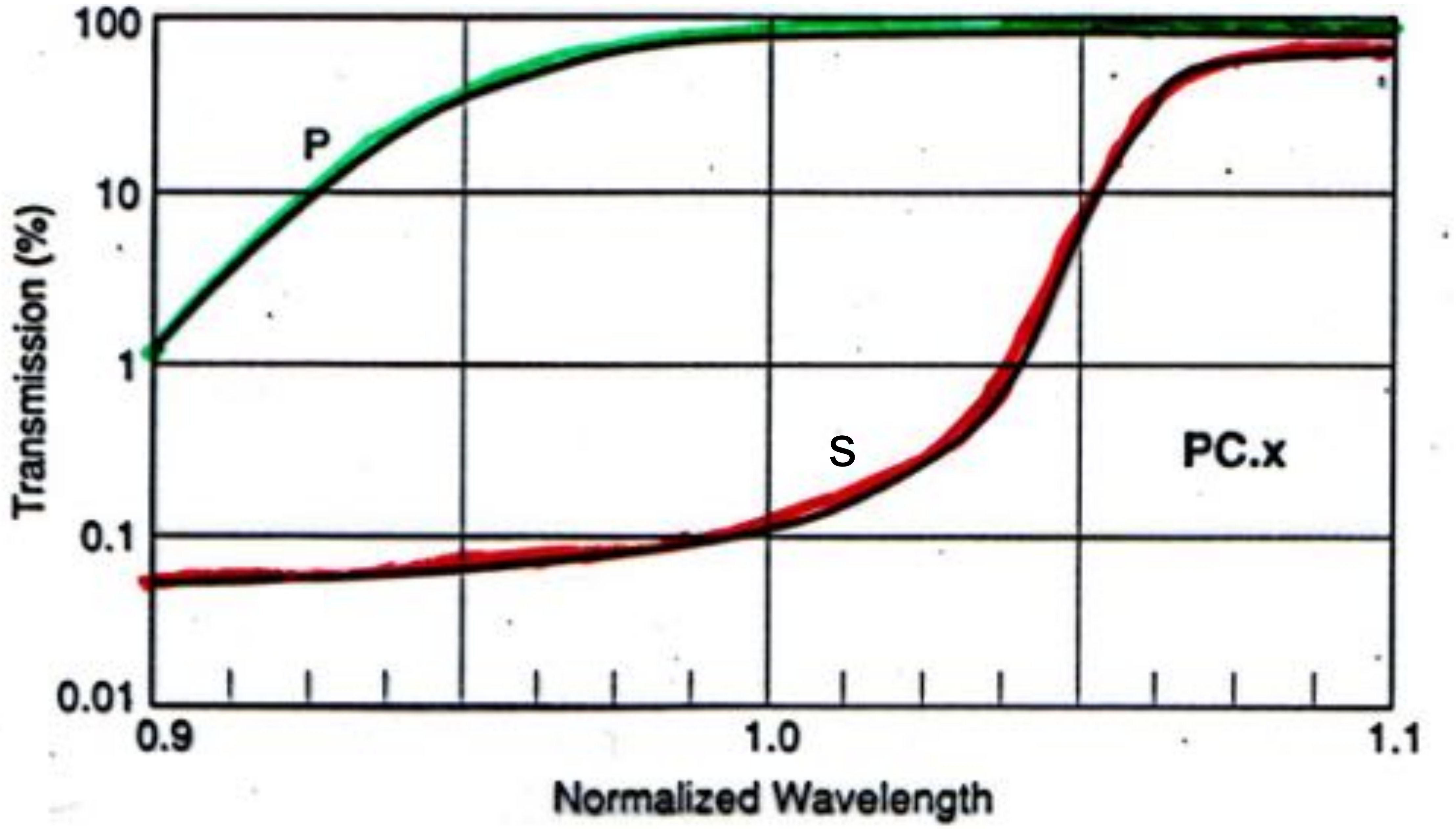
ULTIMA Series Precision Mounts

Wavel
441.6
488–5
532
632.8
670
780
830
1064
1300



Elementy światłodzielące





— wymiary od 10 X 10 X 10 /mm do 50 X 50 X 50 /mm

— zniekształcenia czoła fali $\leq \lambda/4$ (632,8 nm)

— apertura > 80% powierzchni

— transmisja $T_p > 95\%$, odbicie $R_s > 99,8\%$

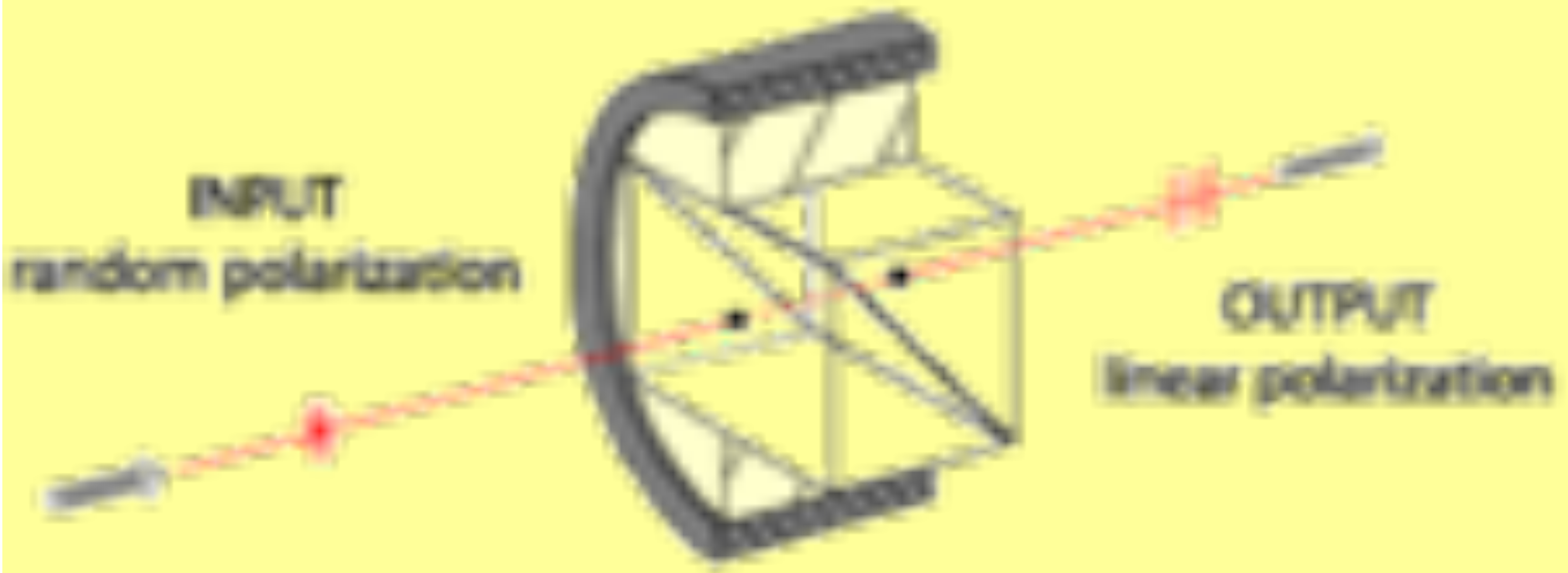
— $T_p/R_s > 1000:1$ silna zależność od długości fali $\mp 0,01(\lambda/\lambda_0)$

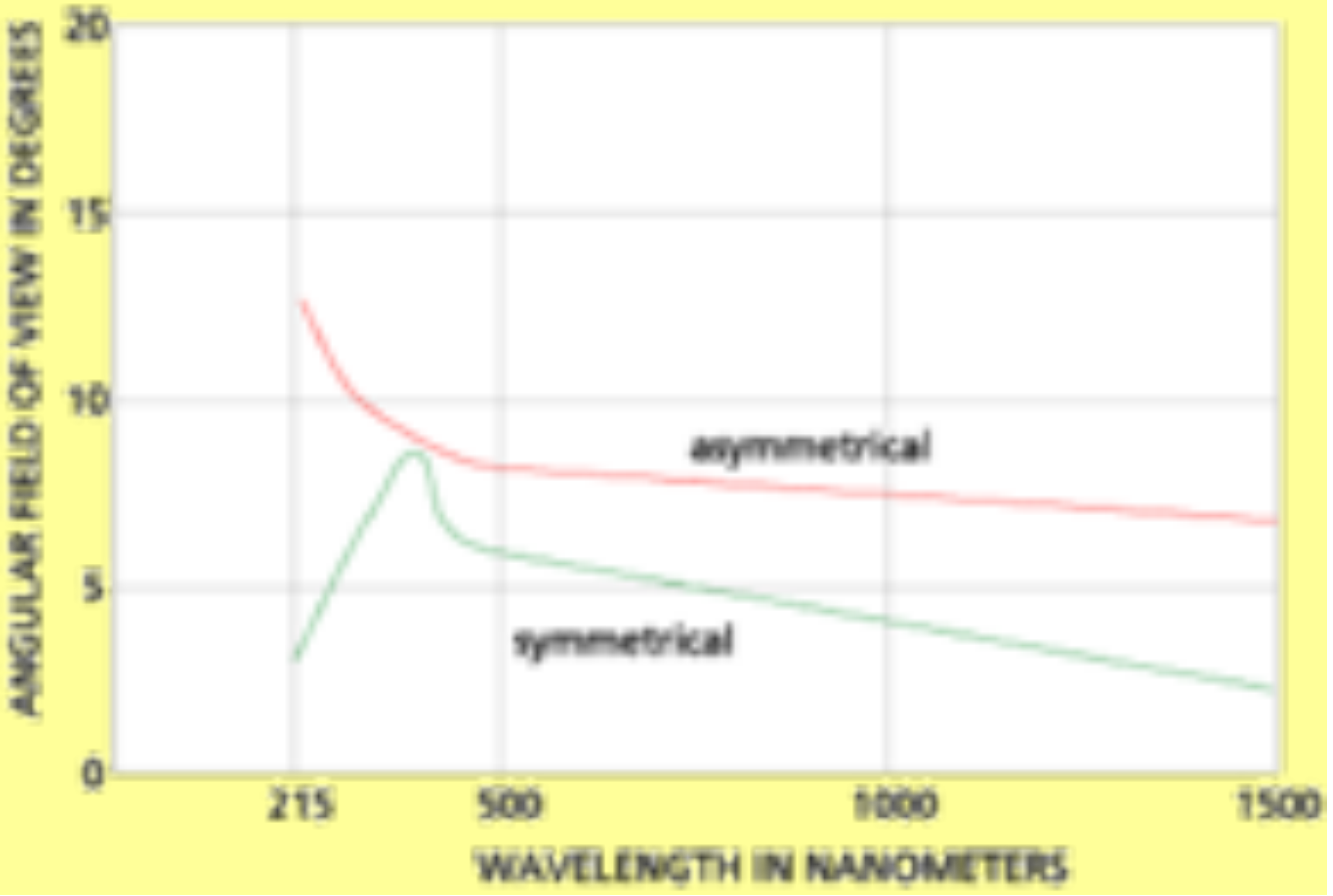
— odchylenie wiązki od pierwotnego kierunku 5’

— tolerancja dla kąta padania $0° \mp 3°$

http://www.mellesgriot.com

Pryzmaty polaryzacyjne





Glan – Taylor prism

http://www.mellesgriot.com

SPECIFICATIONS: WOLLASTON PRISMS

Wavelength Range: 350 to 2300 nm

Calcite Color:
Colorless. Parts coated with Coating Suffix /C may have slightly reduced transmission below 420 nm.

Calcite: Melles Griot optical grade

Transmission (Ratio of Total Output to Total Unpolarized Input):
$(k_1+k_2) = 84\%$

Extinction Ratio (H_{90}): $<1 \times 10^{-5}$

Length/Aperture: 1.0

Separation Angle: See chart

Dimensions: ±0.25 mm

Centration: 10 arc minutes

urface Quality: 80–50 scratch and dig

Mounting:
Cylindrical black anodized aluminum housing with Product Number permanently engraved on side.

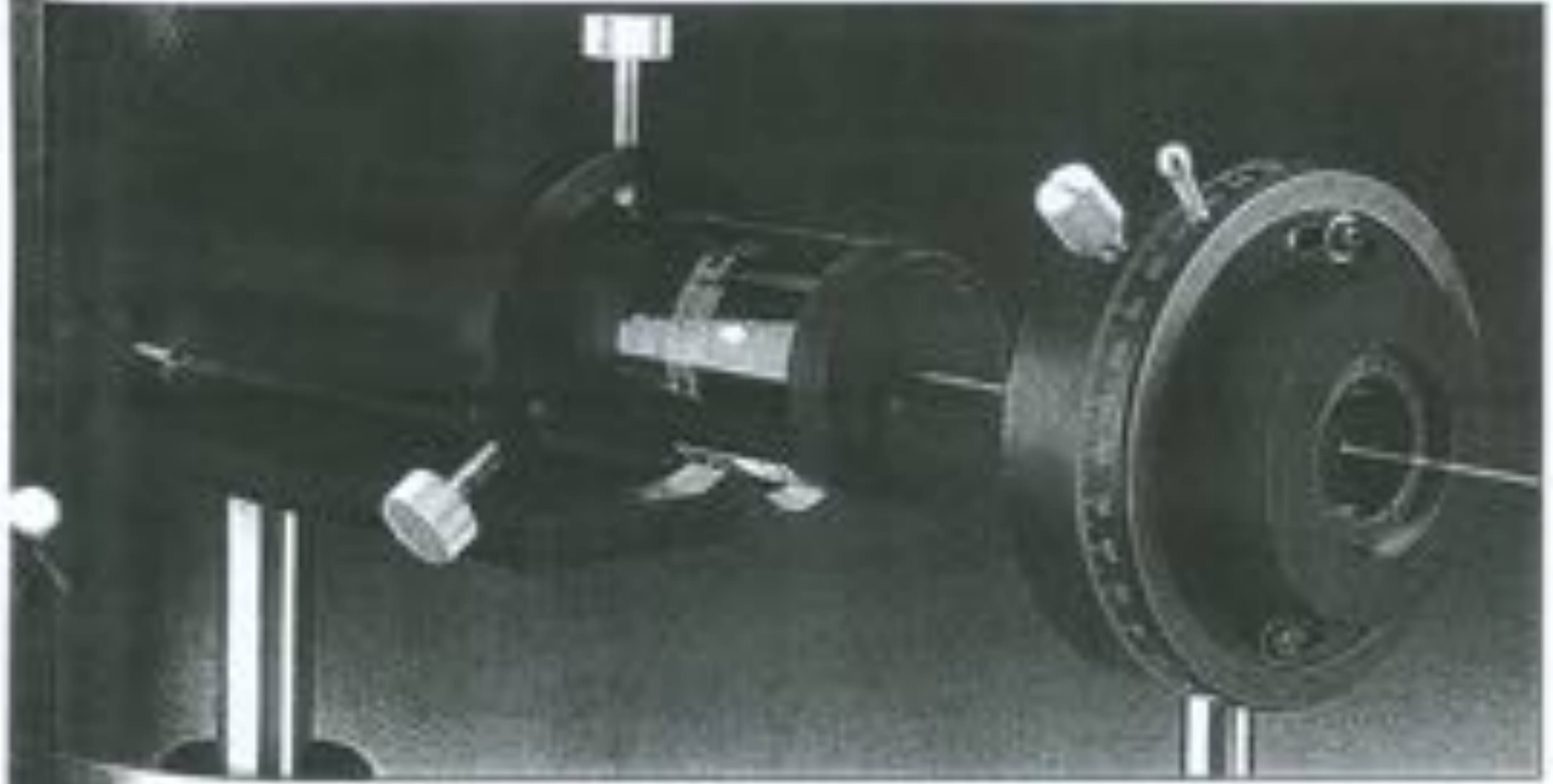
Antireflection Coatings for Polarizing Prisms

Center Wavelength (nm)	Wavelength Range (nm)	Maximum Reflectance (%)	COATING SUFFIX
550	400–700	2.0	/A
830	650–1100	2.0	/C

Wollaston Prisms

Outside Diameter ϕ (mm)	Housing Length L (mm)	Beam Deviation (degrees)	Clear Aperture A (mm)	PRODUCT NUMBER
25.0	13.0	15	10 × 10	03 PPW 001
30.0	18.0	15	15 × 15	03 PPW 003
25.0	12.0	20	10 × 10	03 PPW 012
30.0	17.0	20	15 × 15	03 PPW 014

For antireflection coating append Coating Suffix from table.



RETARDATION PLATES

Retardation plates

When polarized light strikes a birefringent crystal, it is separated into ordinary and extraordinary beams which are polarized perpendicular to each other. Each beam has its own index of refraction, i.e. one of the waves propagates more slowly than the other. After passage through the crystal, they exhibit a phase difference which is proportional to the thickness of the crystal and the difference in the indices of refraction. Careful selection of the material and the thickness of the crystal makes it possible to convert linearly polarized light into any polarization state desired.

Half-wave plates λ/2 and quarter-wave plates λ/4 are the retardation plates most commonly used. Let us examine how they work using crystal quartz as an example.

The electric field vector of a linearly polarized light beam is perpendicularly incident on a plane-parallel quartz plate at an angle of 45° to the optical axis. The optical axis of the quartz plate lies in the plane of the plate. The beam is split into the ordinary and the extraordinary components and, due to the 45° angle between the E vector and the optical axis, both have the same intensity. As the index of refraction n_e of the extraordinary beam is greater than that of the ordinary beam n_o, the extraordinary beam propagates more slowly through the plate thus creating a phase difference between the two beams. If this is π (180°), then the beam resulting from the superposition of the two beams is rotated by exactly 90° with respect to the incident beam. The required plate thickness d can be calculated as follows:

$$\pi = \frac{2\pi}{\lambda}(n_e - n_o)\cdot d$$

Here the difference of the optical paths $n_e \cdot d$ and $n_o \cdot d$ is equal to λ/2 (λ/2 plate, zero order).

For example, for λ = 589 nm one obtains d = 32,6 µm. Naturally phase differences of integral multiples of π and consequently of thickness d give the same result so that one can also use thicker plates which are mechanically more stable, (multiple order plates).

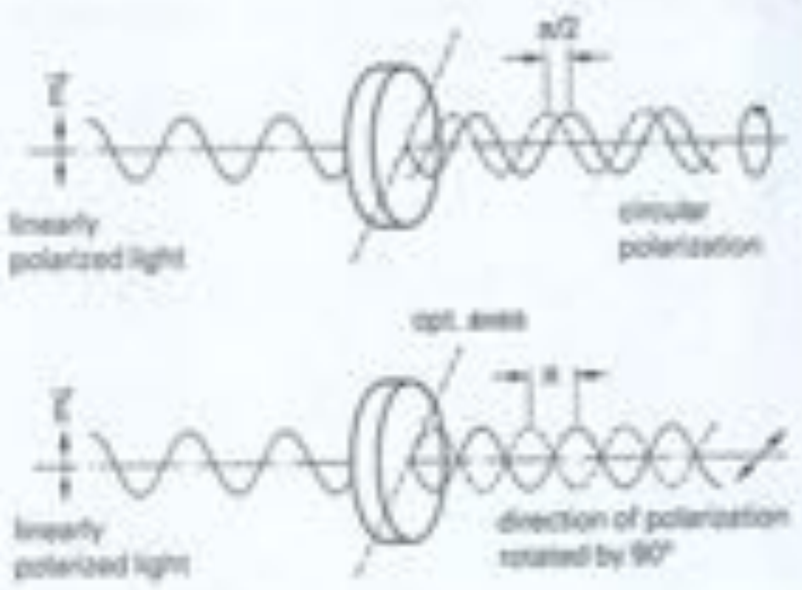
If a plate only half as thick is selected, the phase difference between the two waves will be π/2 (90°) and the light transmitted by the crystal will be circularly polarized (λ/4 plate). This effect also occurs in thicker plates which have odd multiples of π/2 as a phase difference, i.e. they have a thickness of (2K−1) · 16,3 µm, (K = 1, 2, 3 ...).

In order to manufacture a retardation plate, the wavelength must always be known.

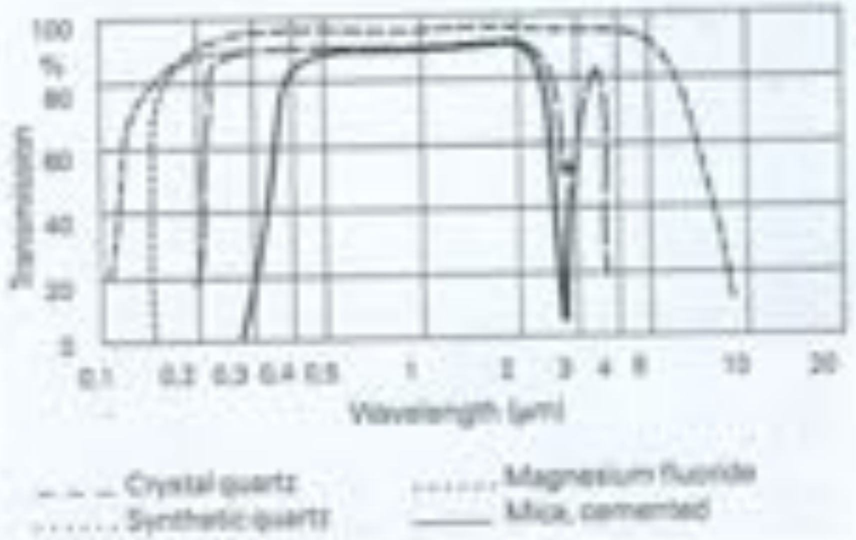
There are many different types of retardation plates available, each type being ideally suited for a particular application. Half-wave plates λ/2 and quarter-wave plates λ/4 are the standard retardation values. Mica, quartz and magnesium fluoride (MgF_2) are the standard materials.

Mica is a material which is frequently used for retardation plates. As the crystals are easy to cleave, very thin plates of zero order can be fabricated. They are cemented between two glass plates in order to increase the mechanical stability. However, mica is not completely transparent and consequently, for high transmission, crystal quartz is used, either as a single plate for a higher order or as a double plate for the zero order.

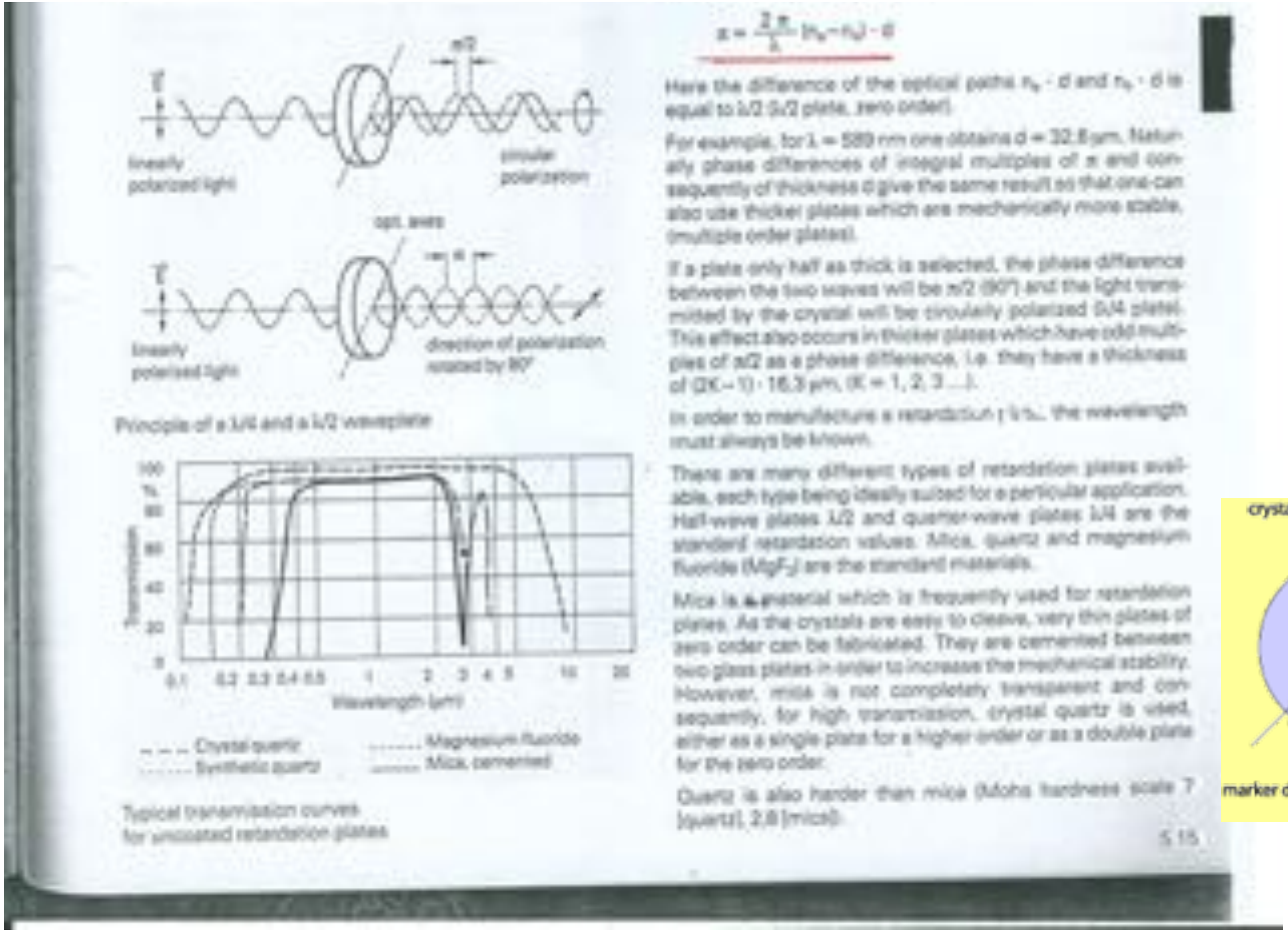
Quartz is also harder than mica (Mohs hardness scale 7 [quartz], 2,8 [mica]).



Principle of a λ/4 and a λ/2 waveplate



Typical transmission curves for uncoated retardation plates



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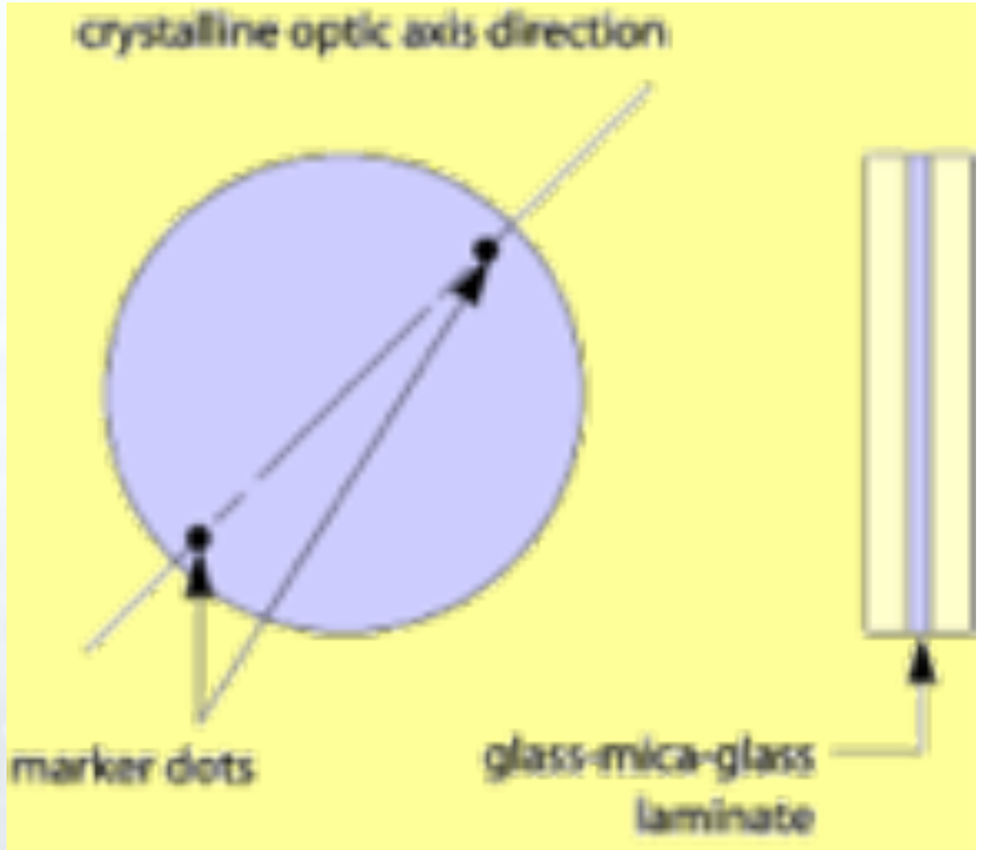
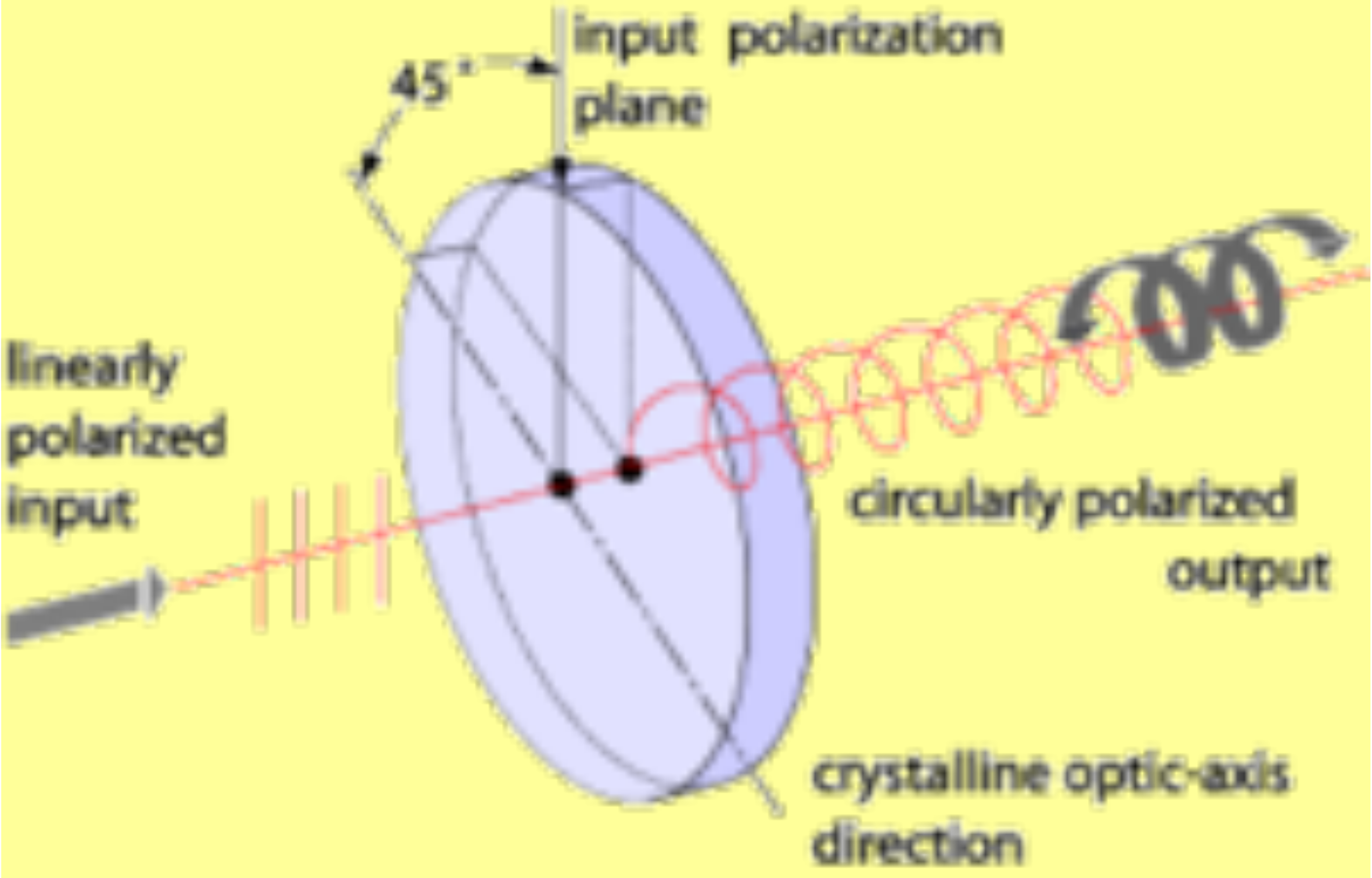
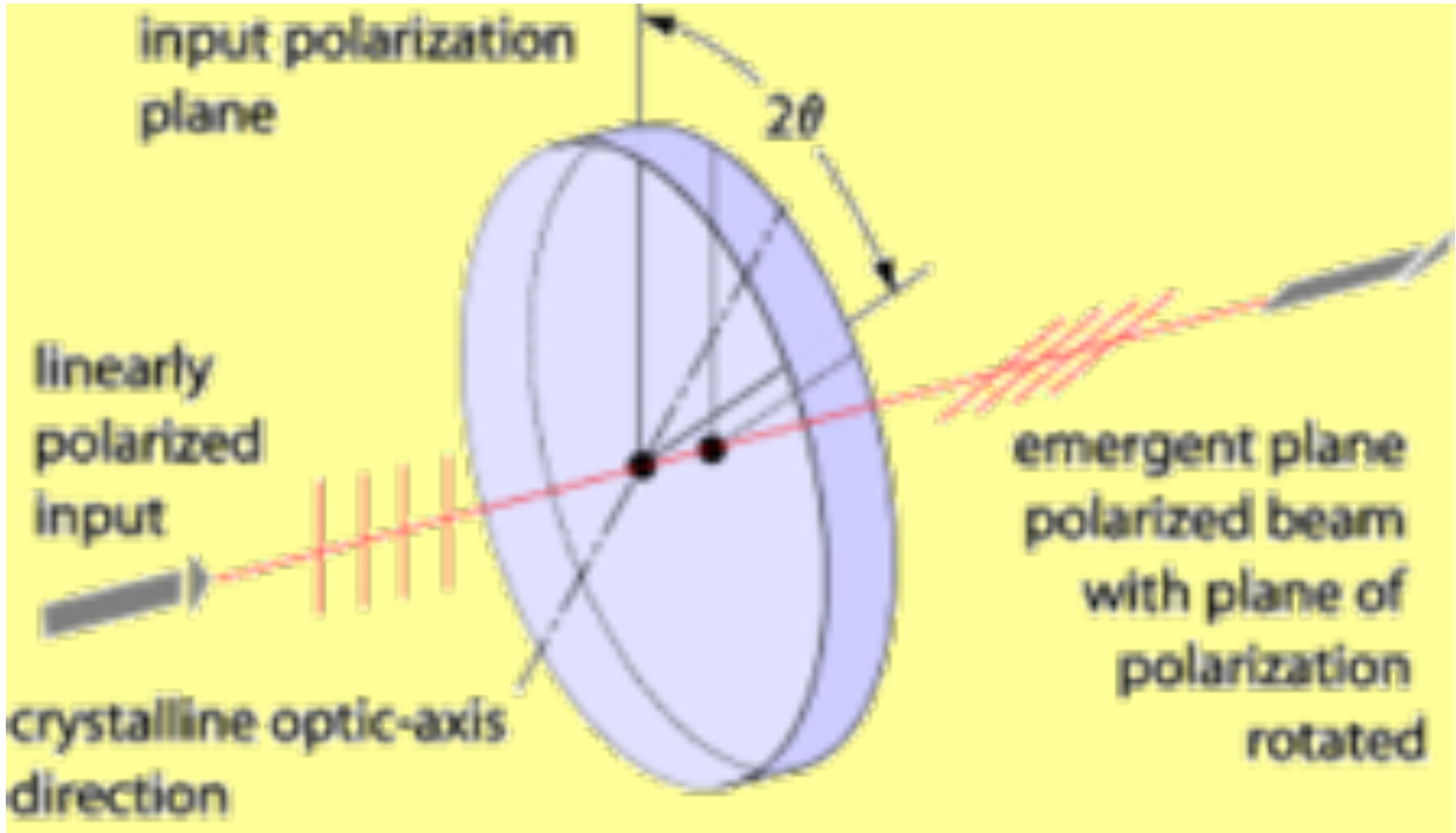



45°
input polarization plane
linearly polarized input
circularly polarized output
crystalline optic-axis direction


input polarization plane
2θ
linearly polarized input
emergent plane polarized beam with plane of polarization rotated
crystalline optic-axis direction

ACHROMATIC FRESNEL RHOMB RETARDERS

Principle of a $\lambda/4$ rhomb

Principle of a $\lambda/2$ rhomb

A birefringent crystal is not the only means to achieve
phase shift between two beams polarized perpendicular
each other. It can also be obtained by total internal reflecti
at an interface, for example, between glass and air. This
fect is used in a Fresnel rhomb. Plane-polarized light who
plane of polarization is diagonal to the entrance surface h
two equal components parallel and perpendicular to t
plane of incidence of the glass-air interface. The angle of i
dence at the interface is determined by the angle of t
rhomb such that, in accordance with the Fresnel equati
after 2 total internal reflections a phase shift of 90° ($\lambda/4$) b
ween the two components is achieved. The emerging ligh
circularly polarized. If the plane of polarization of the incid
light is not exactly diagonal to the entrance surface then el
tically polarized light will be produced. Therefore, it is to yo
advantage to mount a Fresnel rhomb in a rotation mount.
the phase shift depends on the refractive index of the ma
rial alone, the Fresnel rhomb is only suitable for a limit
wavelength range due to dispersion.

Placing two $\lambda/4$ rhombs in series will result in a phase shift
$\lambda/2$, i.e. a 90° rotation of the plane of polarization. Thus a
rhomb consists of two $\lambda/4$ rhombs which are eit
cemented or have an air-space, depending on the power
quirements (see prism polarizers).

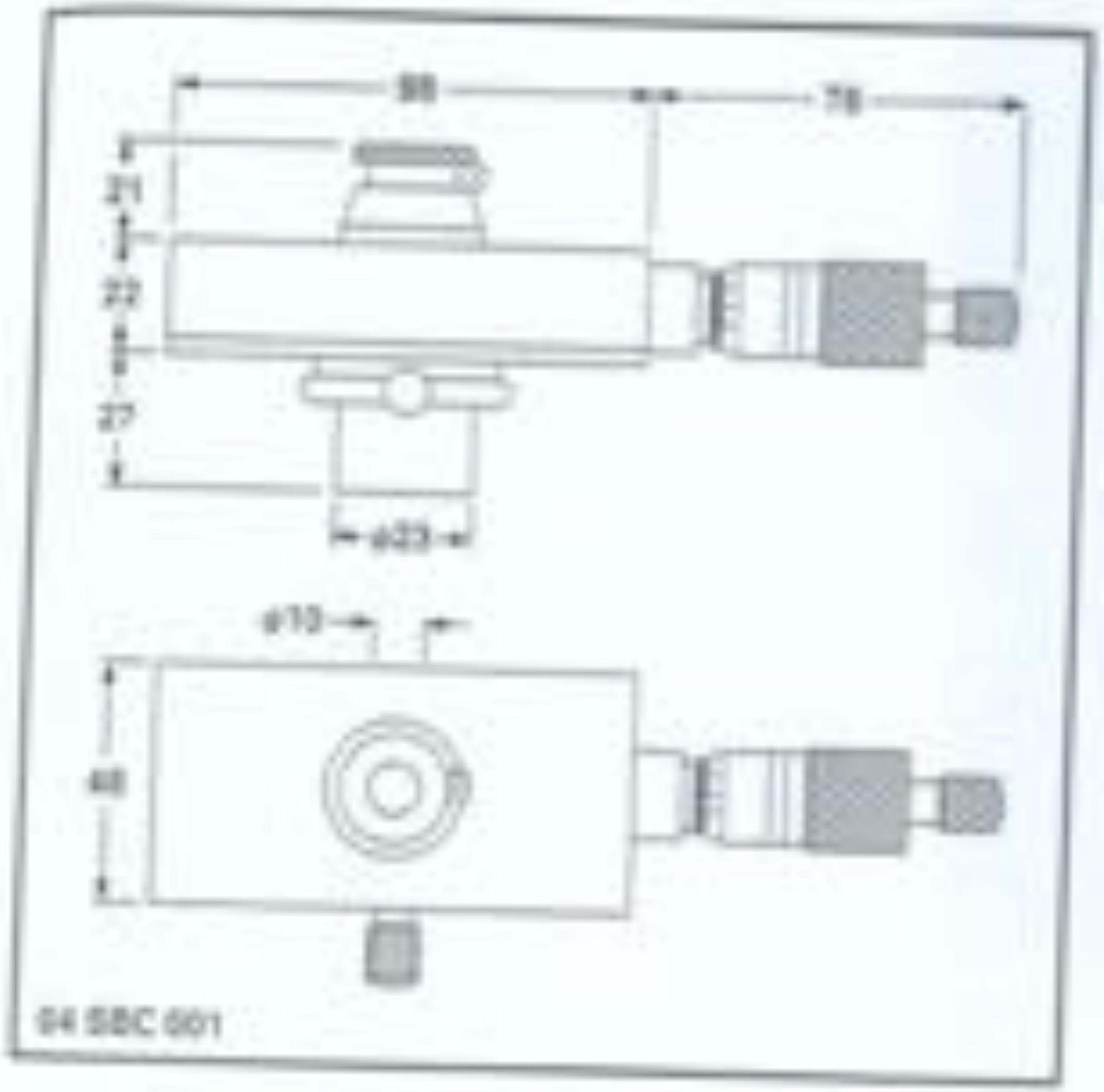
**Rhombs for the Wavelength Region between 237 a
2000 nm**

The dispersive properties of the rhomb material leads to a
viation from the nominal retardation of usually less than
for the 237 to 2000 region. The error is smallest for the cen
wavelength. However, stress birefringence in materials a
causes a slight shift of the retardation.

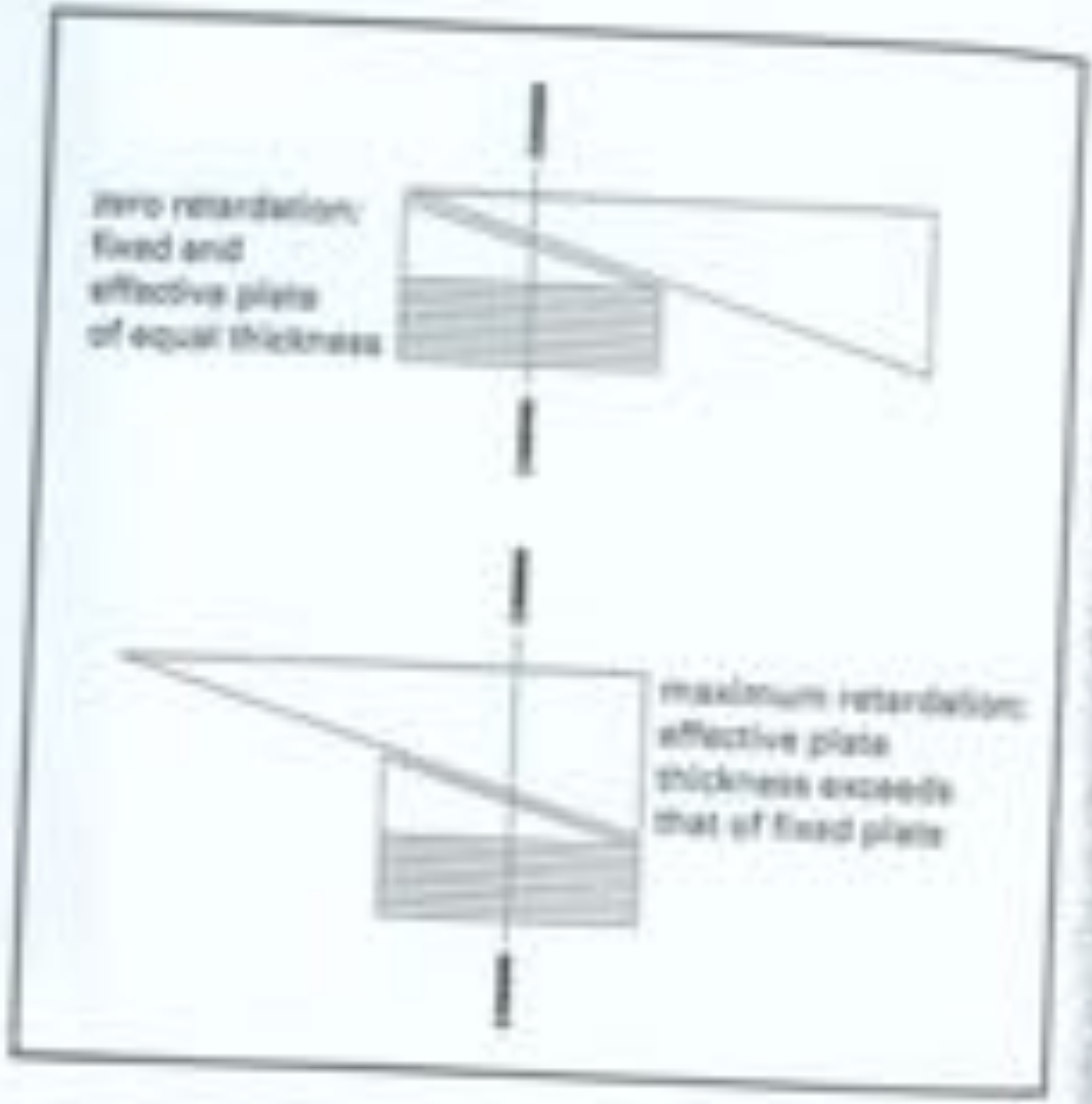
In cemented $\lambda/2$ rhombs for wavelengths below 300 nm,
cement transmits 80% at 220 nm. In the other $\lambda/2$ rhom
the cement transmits 80% at 280 nm and less for sho
wavelengths. Air-spaced rhombs are always delive
mounted.

Just as for retardation plates, the Fresnel rhombs can
supplied with ARBE, ARSD, ARSM or ARBM anti-reflec
coatings. (See page S 16)

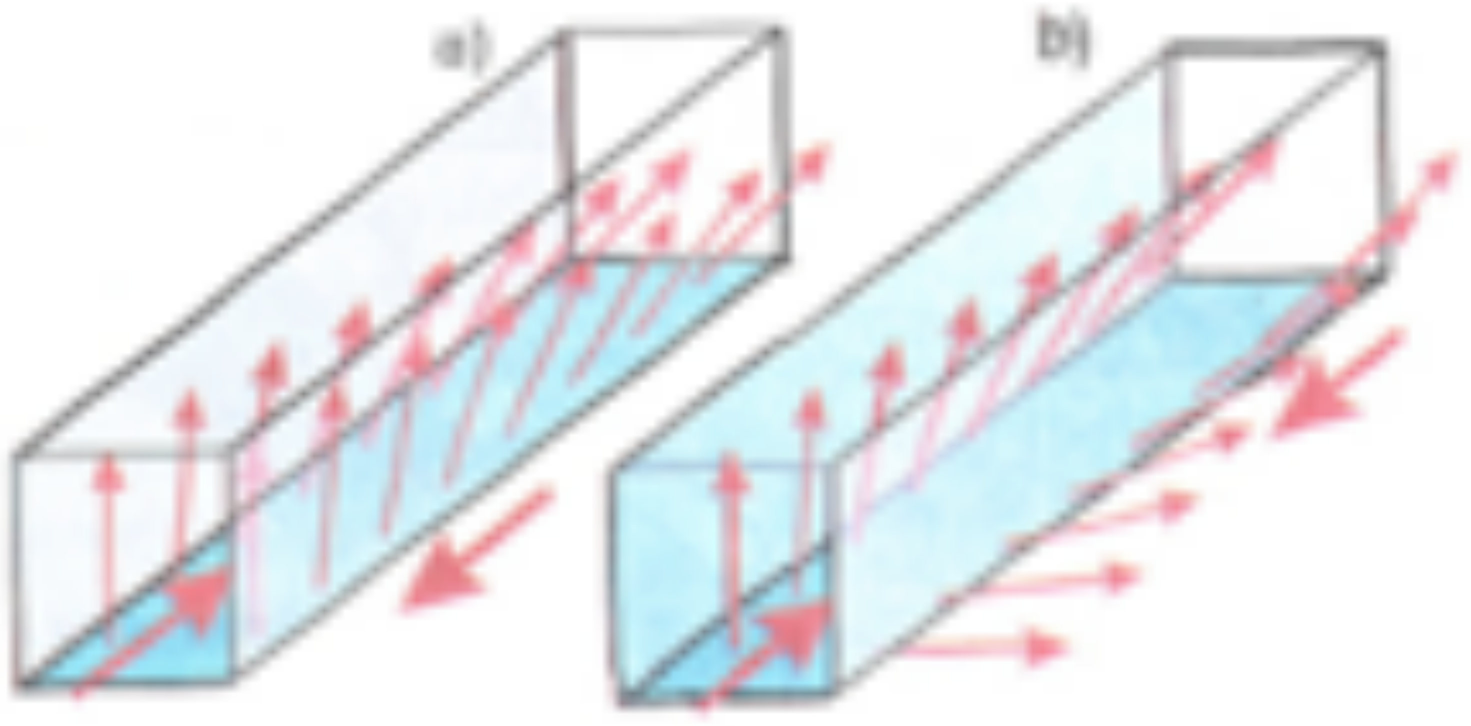
Soleil-Babinet Compensator and Divided Circle Rotating Mount



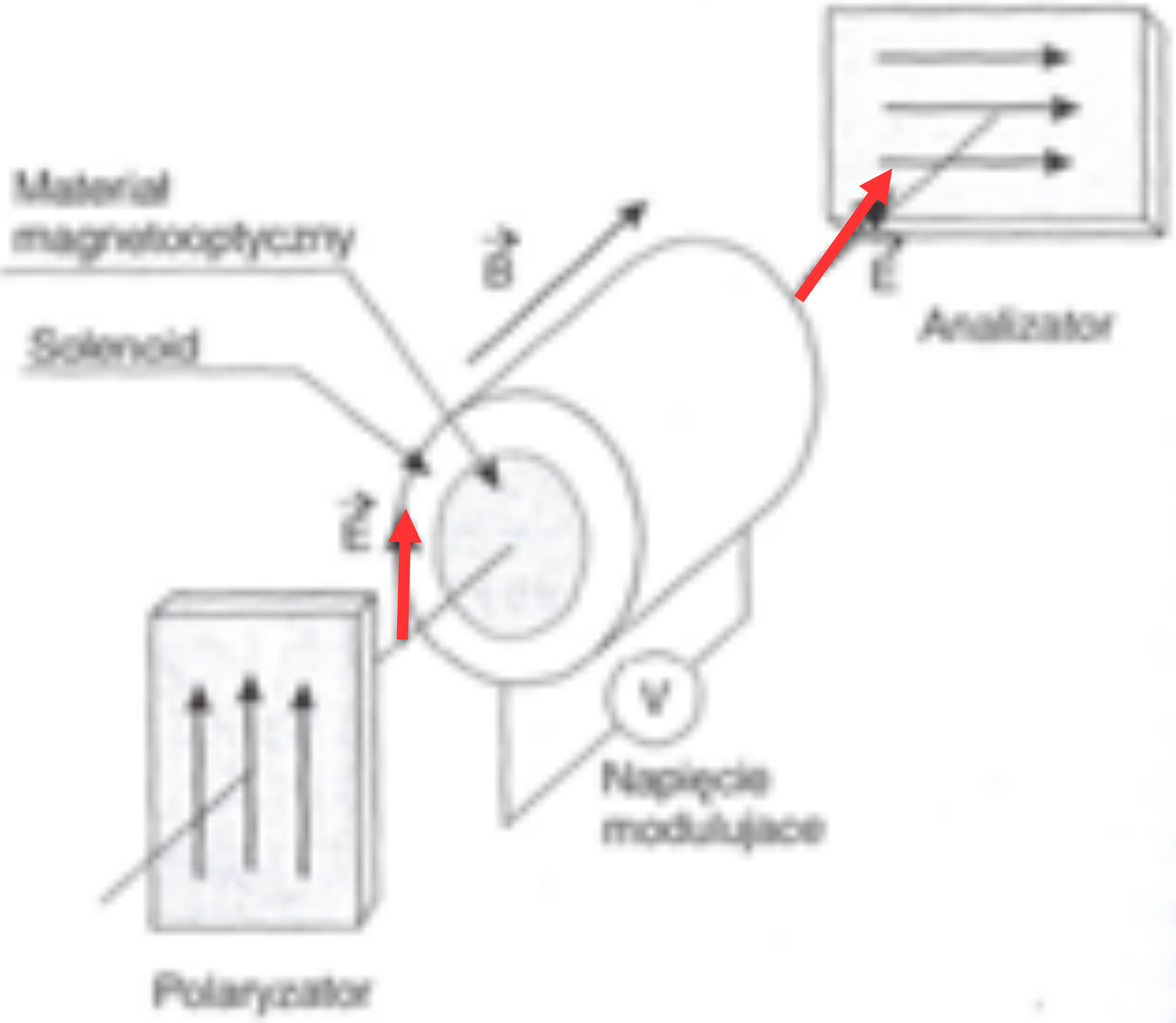
04 SBC 001



Rotator Faraday'a



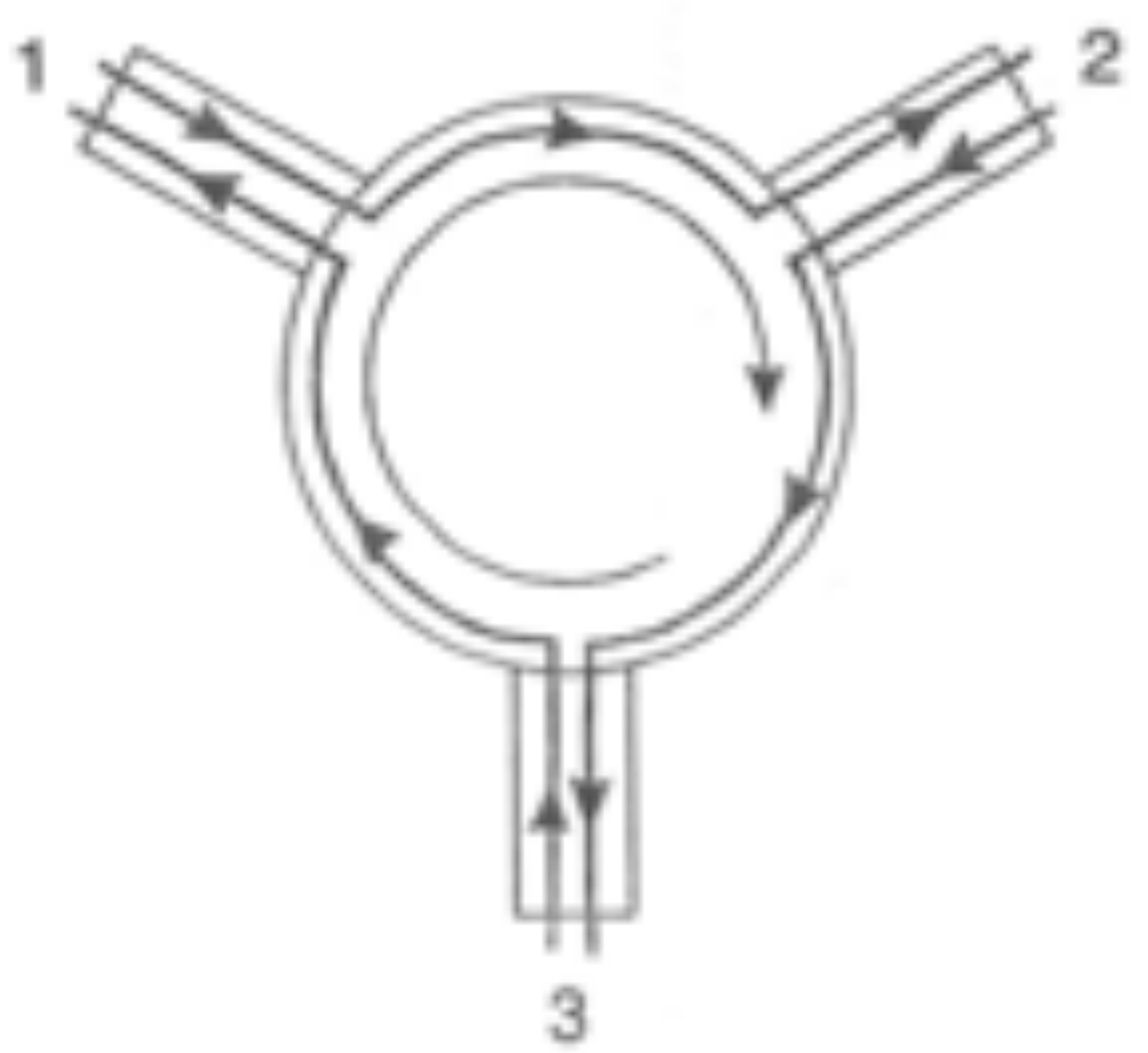
Rys. V.43. Skręcenie płaszczyzny pionowo spolaryzowanego światła przy przejściu przez płytkę kwarcową (a) i przez rotator Faradaya (b)



Rys. III.6. Modulator Faradaya

B.Ziętek *Optoelektronika,* **Wydawnictwo UMK Toruń 2005**

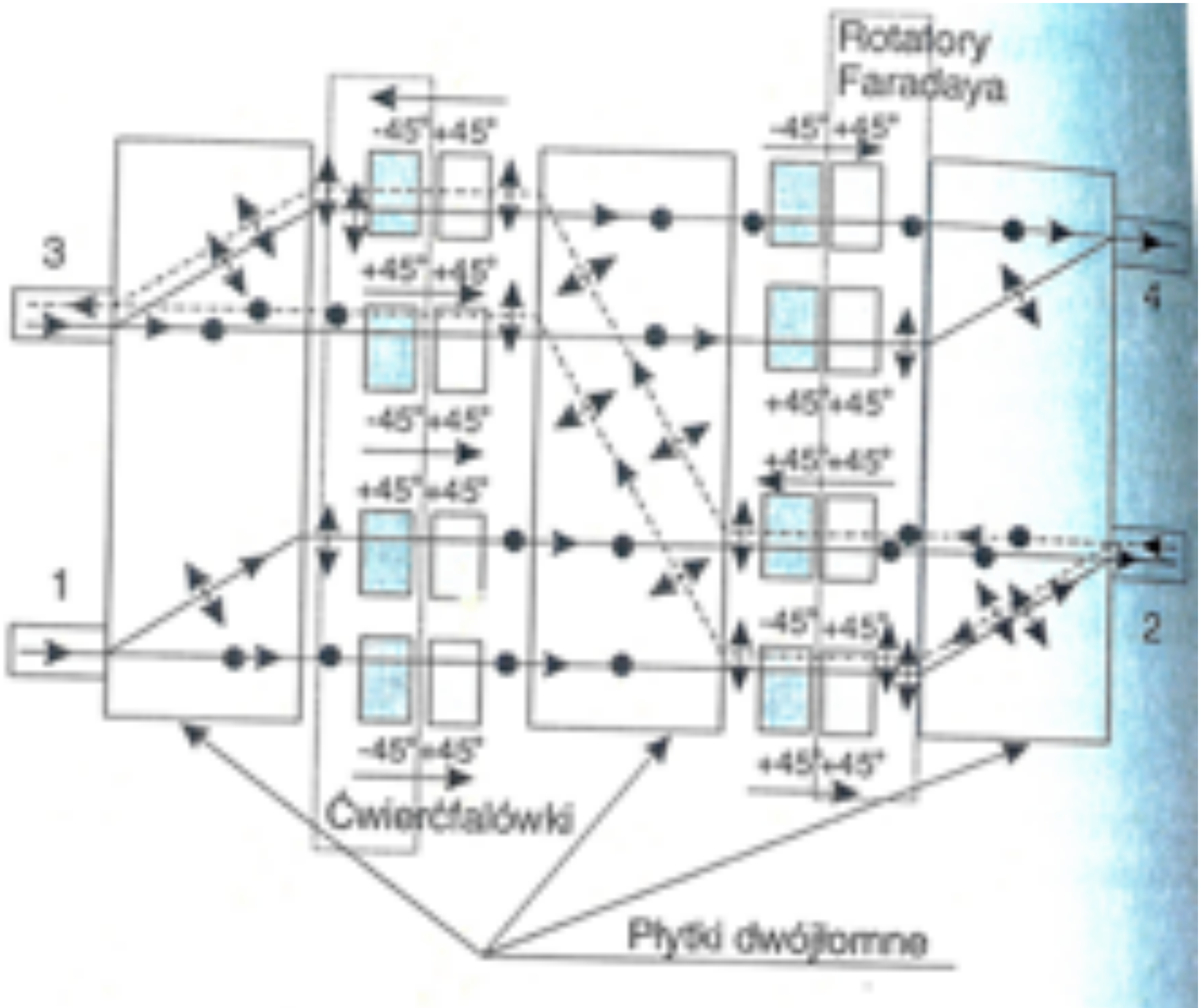
Cyrkulator optyczny



.52. Schemat ideowy cyrkulatora doskonałego

B.Ziętek *Optoelektronika,* **Wydawnictwo UMK Toruń 2005**

Cyrkulator optyczny



Rys. IV.53. Schemat cyrkulatora optycznego (za [37])

B.Ziętek *Optoelektronika*, **Wydawnictwo UMK Toruń 2005**

Polaryzacja światła przez rozpraszanie