

Cristallografia Ottica

Figure e testi tratti da:

Bloss: Introduction to the methods of Optical Cristallography.

Wenk-Bulakh: Minerals, their constitution and origin.

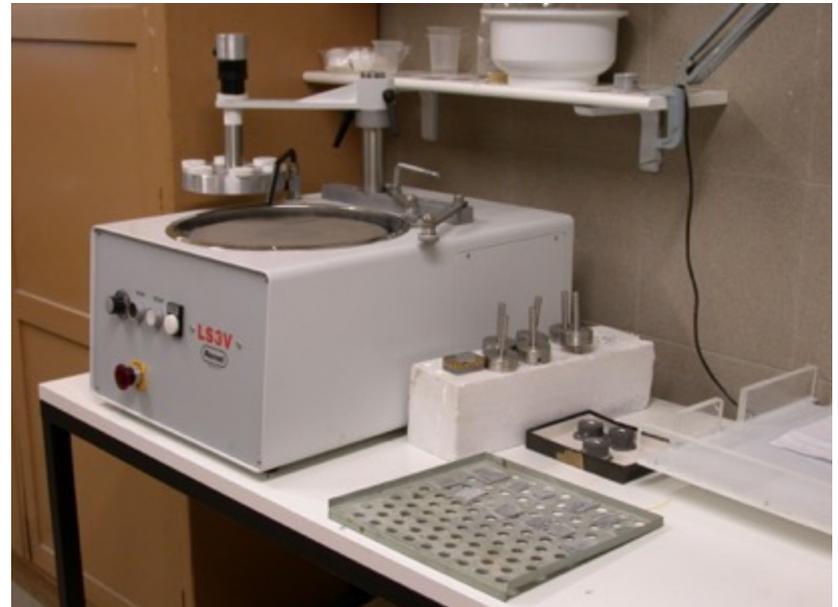
Preparazione delle sezioni sottili





**Macchina troncatrice ed
assottigliatrice**

Macchina levigatrice

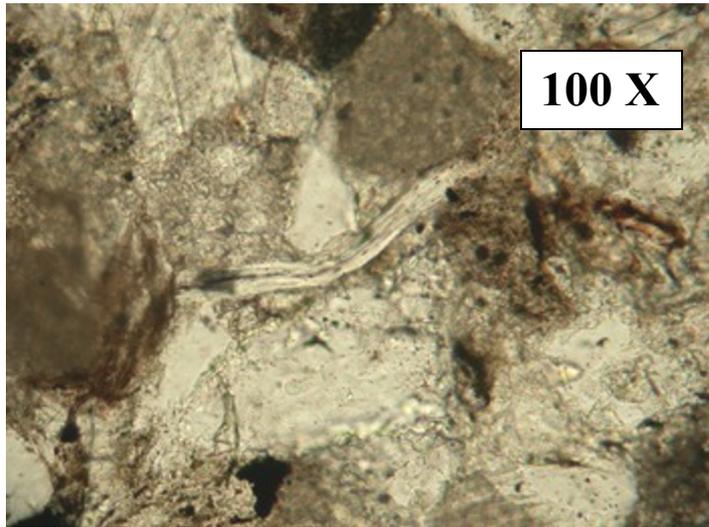




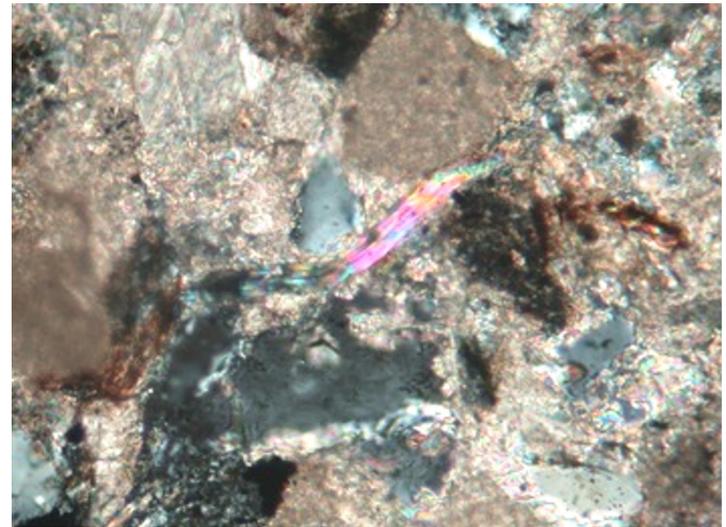
Lucidatura mediante pasta abrasiva

**Sezioni con spessore di
0.03 mm**

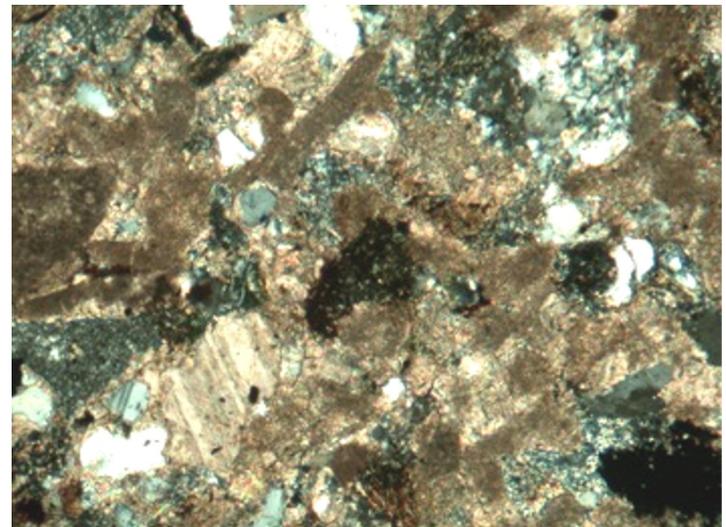
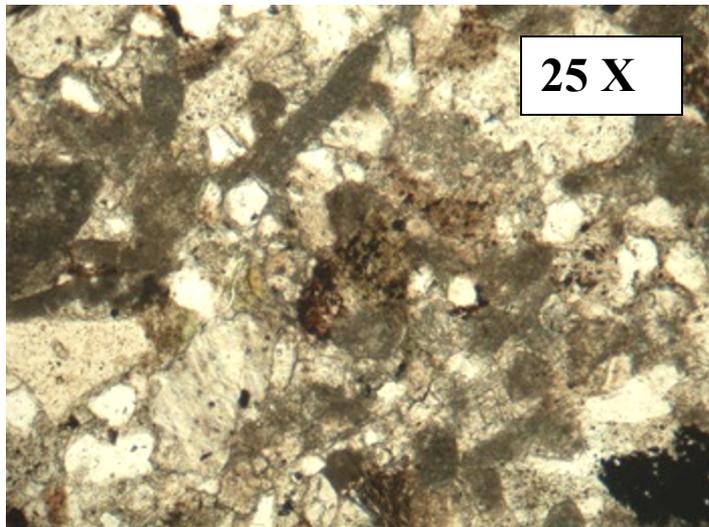




Al solo polarizzatore

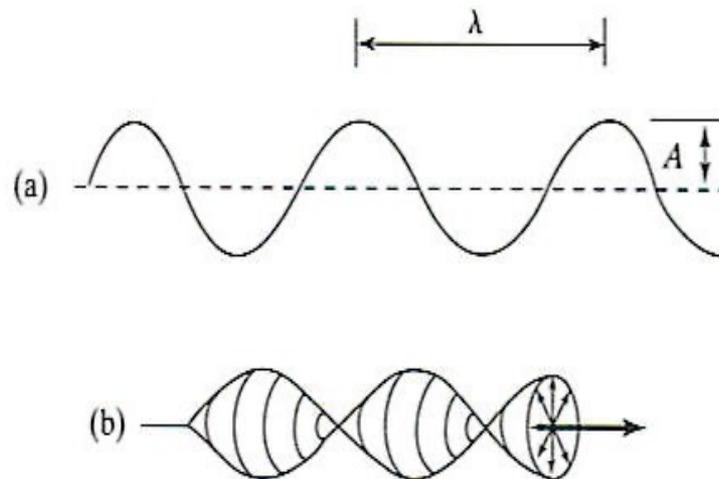


Con polarizzatore e analizzatore



Natura della Luce

- ◆ La luce visibile è una forma di radiazione elettromagnetica, che può essere spiegata come una serie di impulsi o onde di energia elettrica.
- ◆ Viaggia in linea retta con un moto ondoso trasversale.



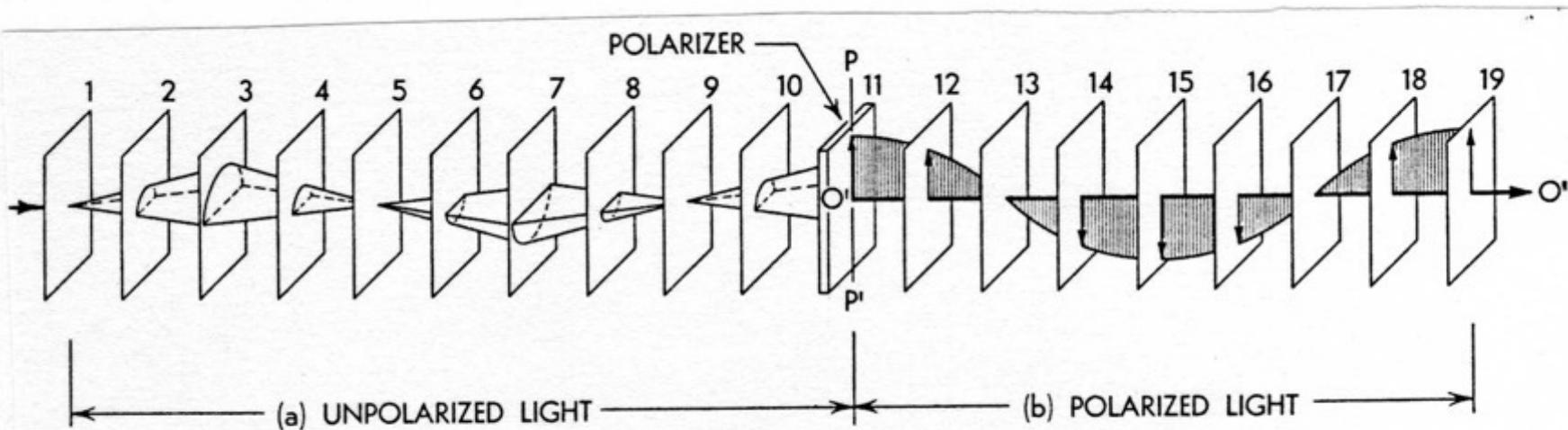


Fig. 1-3. Unpolarized light traveling through imaginary planes 1 to 10 is polarized by a polarizer located at 11. After passing through the polarizer, the light vibrates exclusively parallel to PP' , the privileged direction of the polarizer.

Attributi della Luce

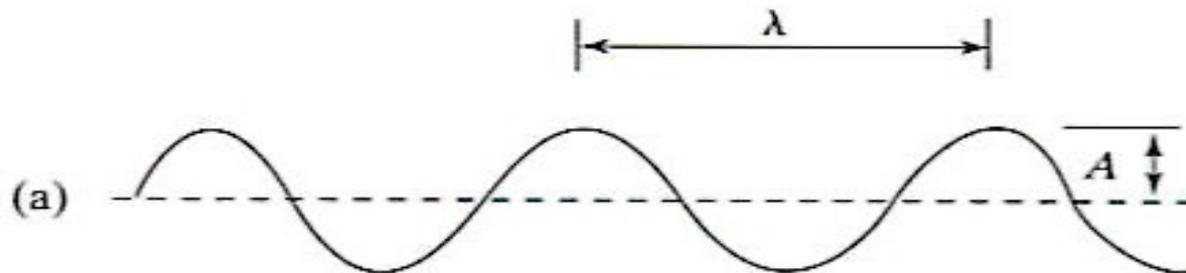
Lunghezza d'onda (λ) – distanza tra due picchi d'onda; si misura in angstroms (\AA); definisce il colore della luce.

Ampiezza (A) – altezza dell'onda luminosa; corrisponde all'intensità/luminosità della luce.

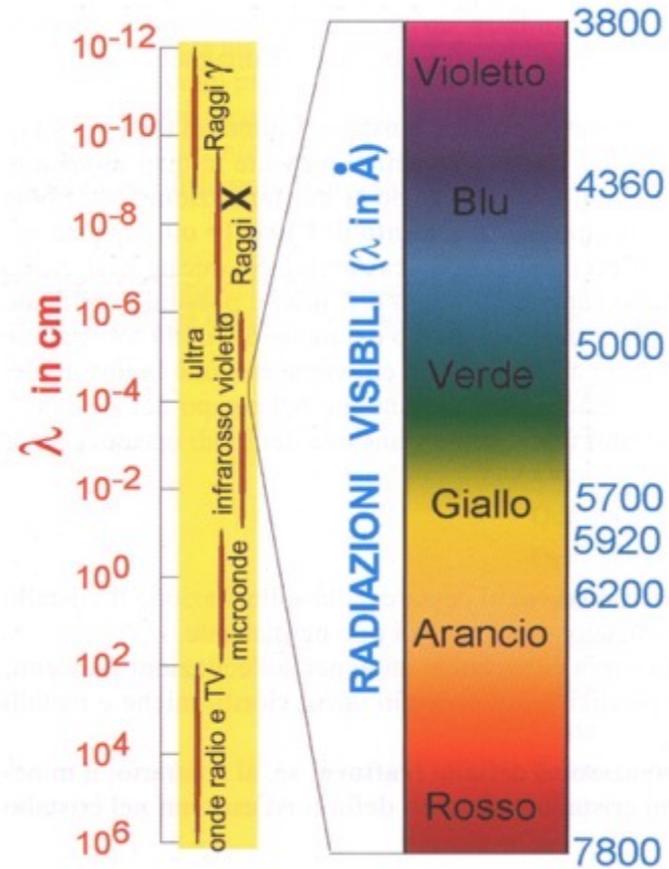
Frequenza (f) – numero di onde luminose che passano per un punto fisso per secondo; si misura in cicli per secondo.

Velocità ($v = f \cdot \lambda$); velocità della luce nel vuoto = $3 \cdot 10^{18} \text{\AA}/\text{sec} = c$; cioè per la luce arancione nel vuoto, $\lambda = 6000 \text{\AA}$, $f = 5 \cdot 10^{14} / \text{sec}$.

La luce rallenta quando passa attraverso sostanze più dense. Poiché la frequenza della luce non cambia mai mentre passa attraverso diverse sostanze, ($f = v/\lambda$) una diminuzione della velocità della luce riflette una diminuzione proporzionale della sua lunghezza d'onda.



SPETTRO ELETTROMAGNETICO



λ = lunghezza d'onda

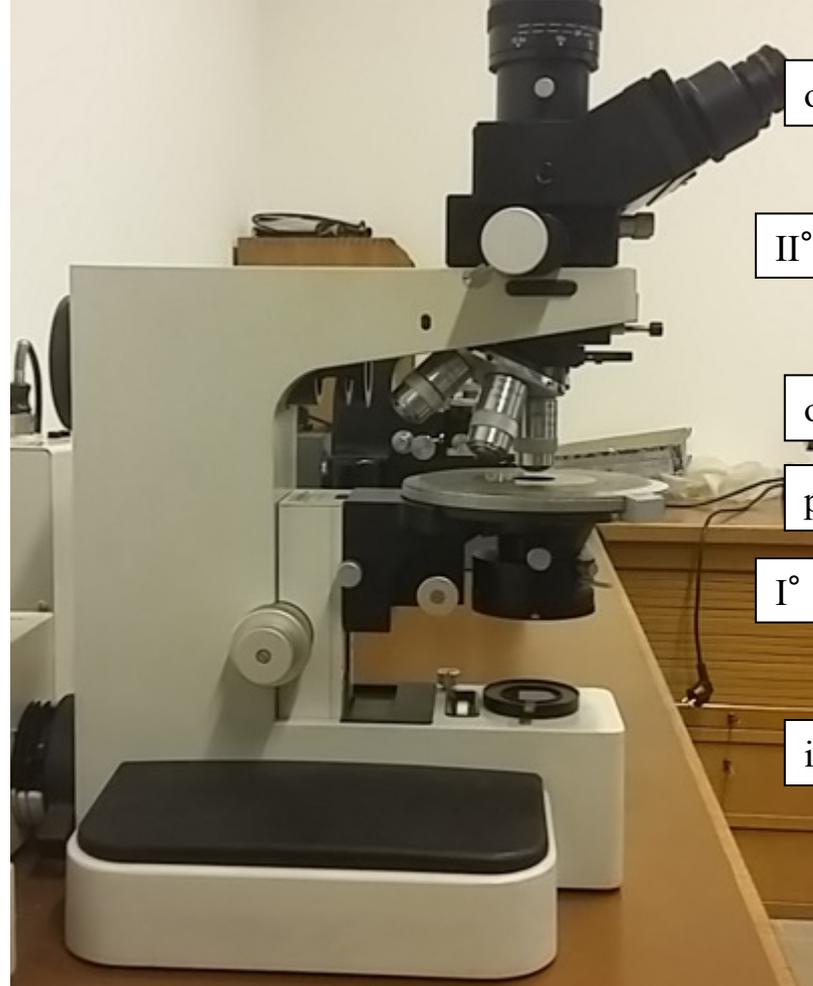
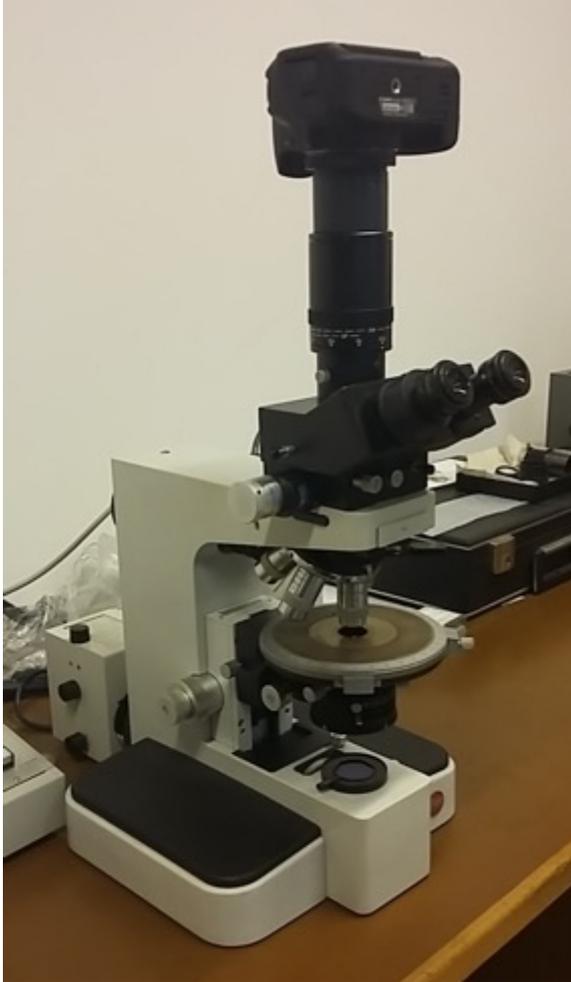
$\lambda = 7800 \text{ \AA}$ (rosso) - 3800 \AA (violetto)

1 Angstrom = $1 \text{ \AA} = 10^{-7} \text{ mm}$

λ rosso = 0.00078 mm

λ violetto = 0.00038 mm

Microscopia ottica: microscopio da mineralogia



oculari

II° polarizzatore

obiettivi

piatto

I° polarizzatore

illuminatore

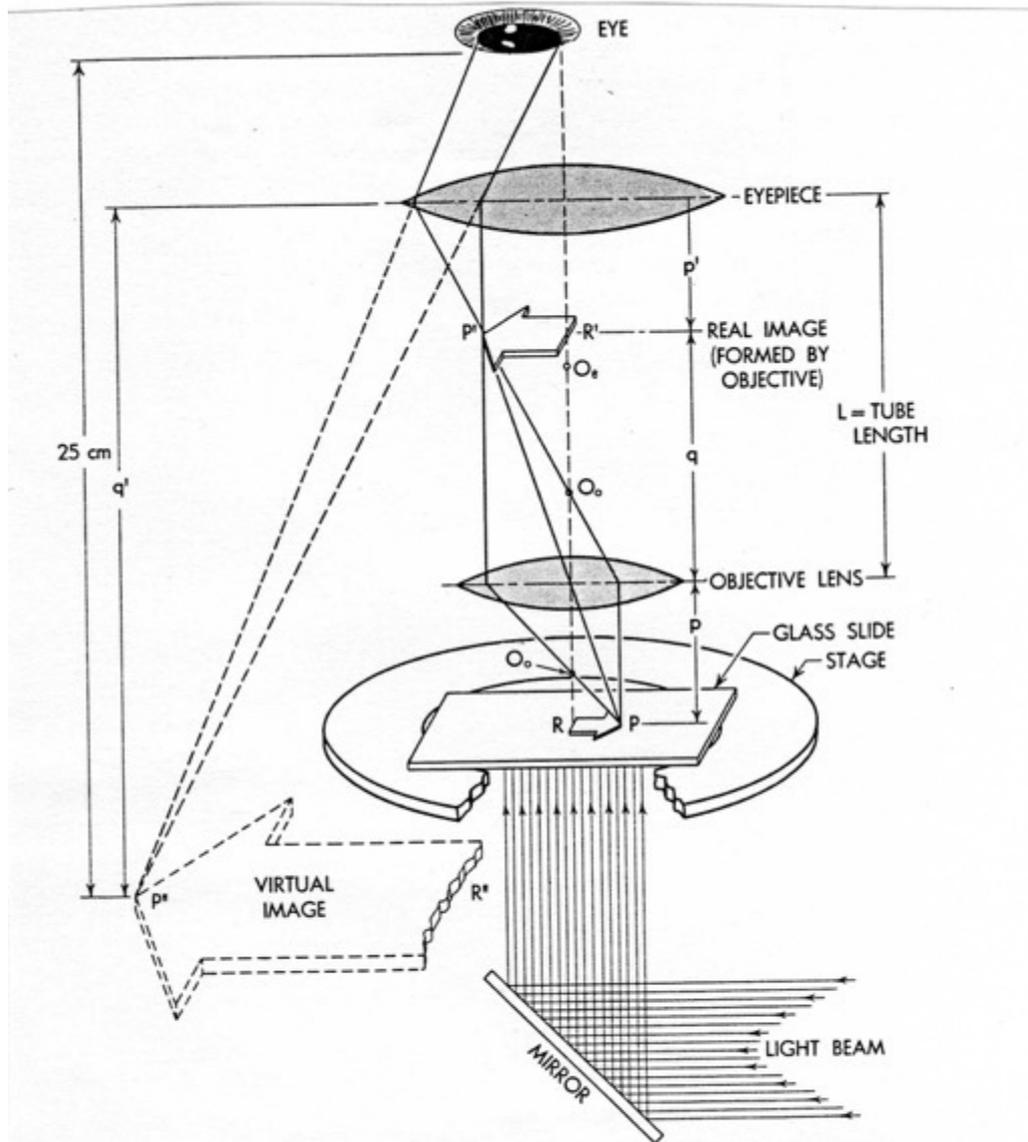
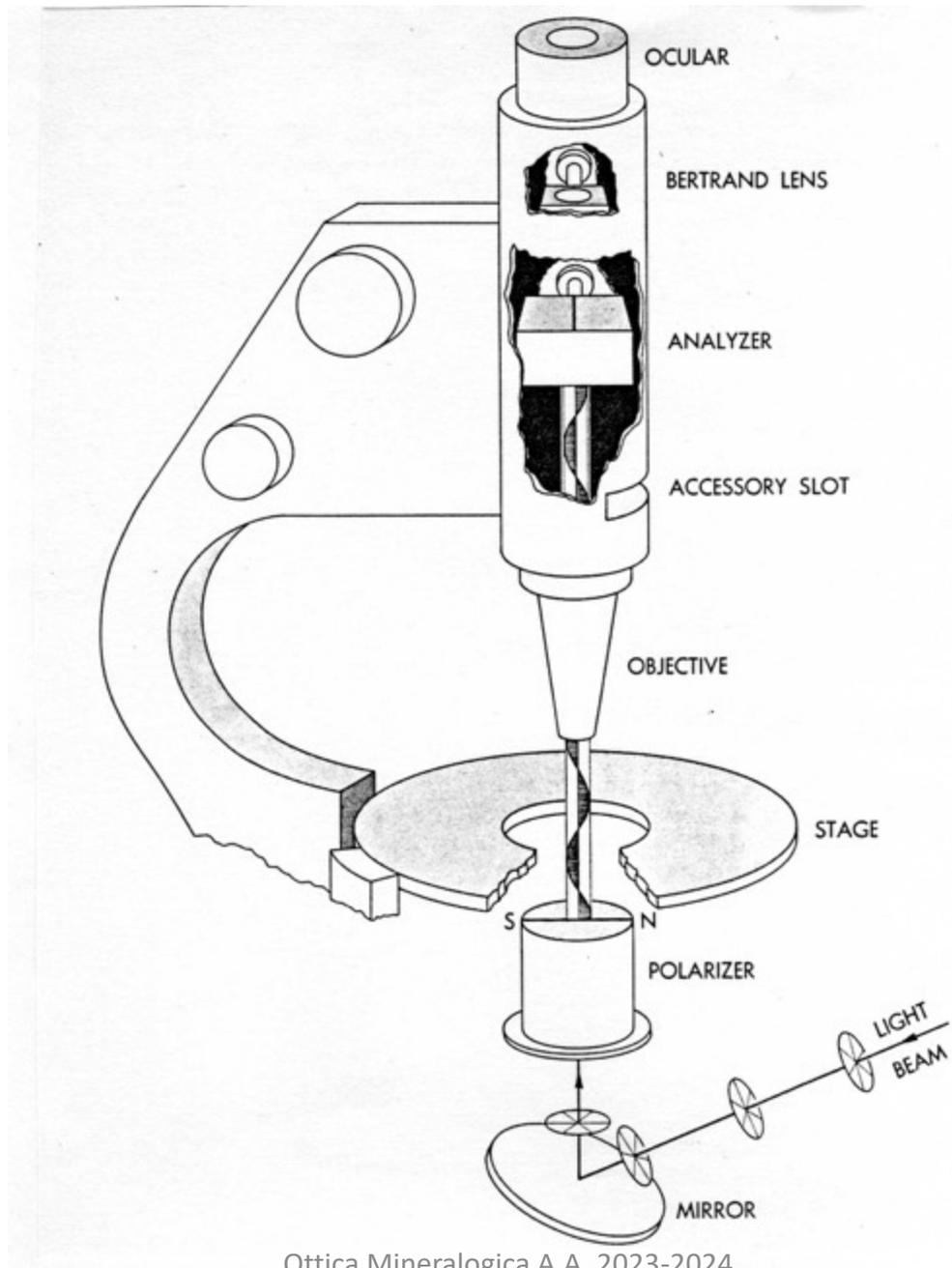
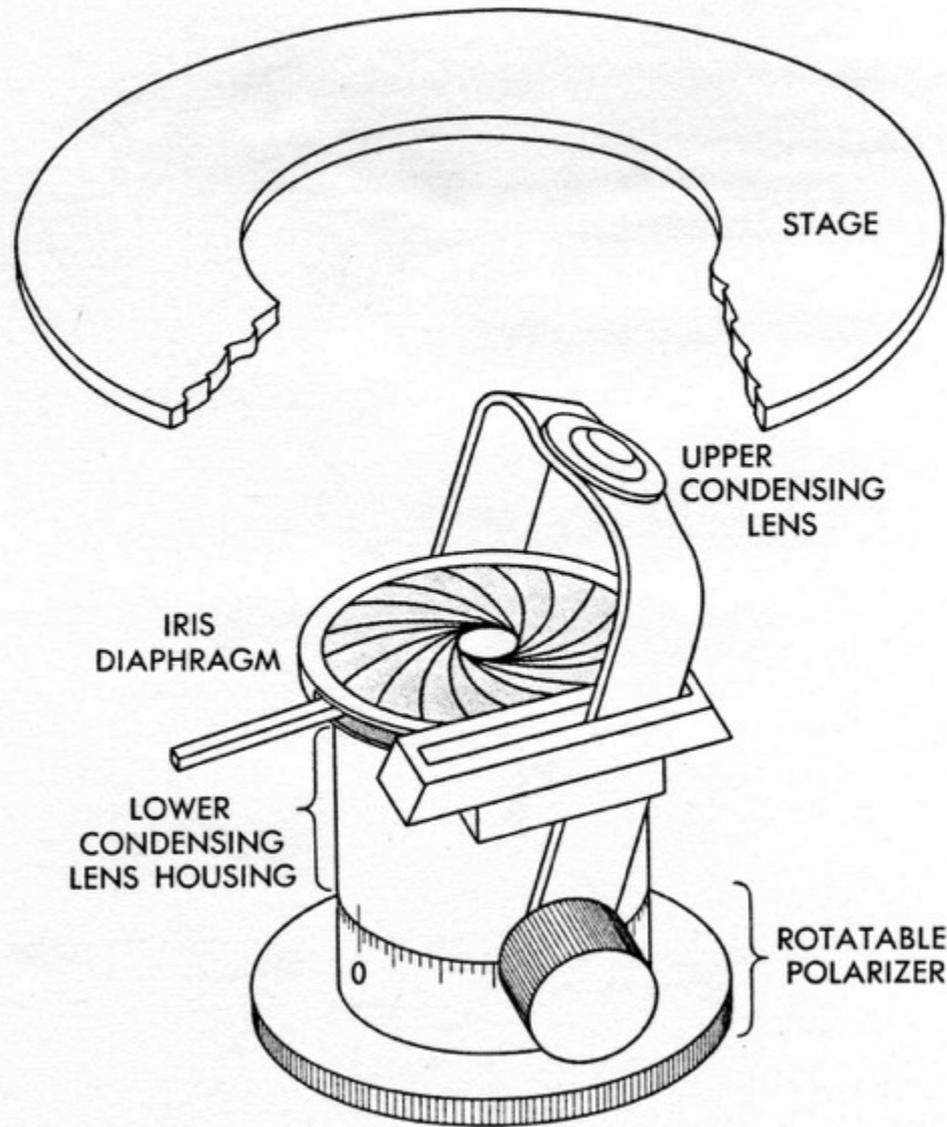


Fig. 3-6. The elements of a compound microscope as shown by a combined perspective view (stage, object RP , images $P'R'$ and $P''R''$) and cross-sectional view (rays, mirror, and lenses). The optical tube length, L , has been disproportionately shortened for illustrative purposes only.





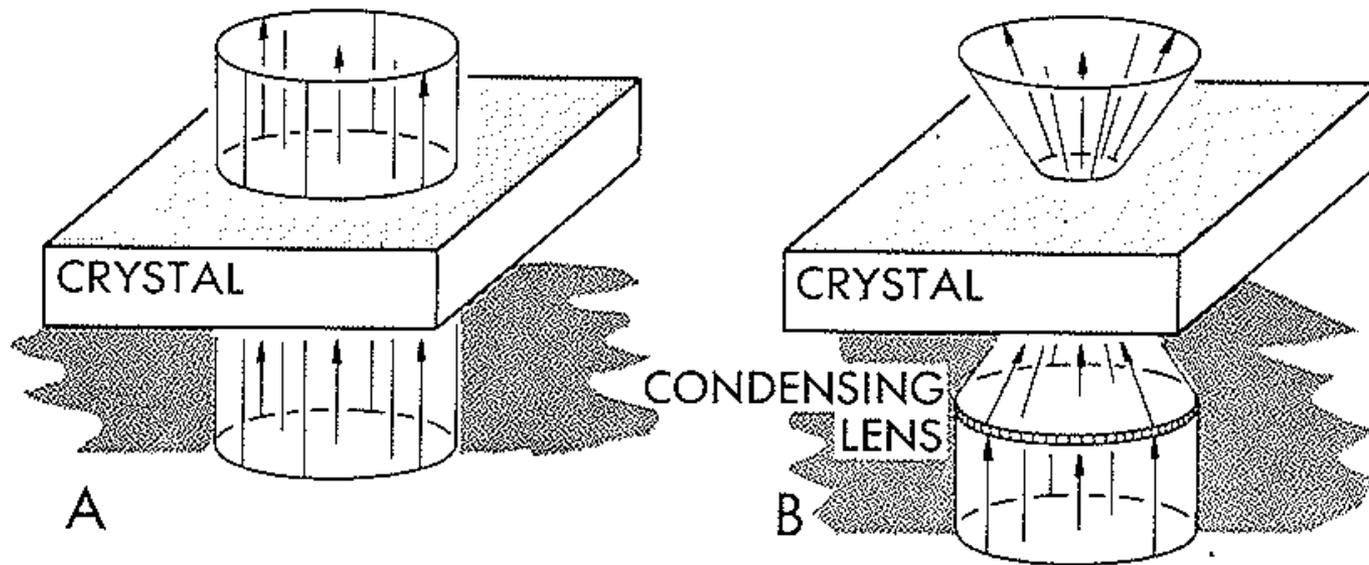


Fig. 7-10. Comparison of the ray paths for orthoscopic illumination (A) and conoscopic illumination (B). For the actual situation the rays shown in (A) would be slightly convergent. They become increasingly parallel, however, as the apertures are decreased (for example, by closing down the iris diaphragm or inserting a lower power lens).

Riflessione e rifrazione dei raggi.

Un raggio incidente sulla superficie di due mezzi isotropi, generalmente produce un raggio riflesso e uno rifratto.

Più un mezzo è denso minore sarà la velocità di propagazione della luce al suo interno.

Il rapporto tra la velocità della luce nel vuoto e la velocità della luce nel mezzo si chiama **indice di rifrazione**:

$$n=c/v$$

n aria = 1

n mezzi sempre >1

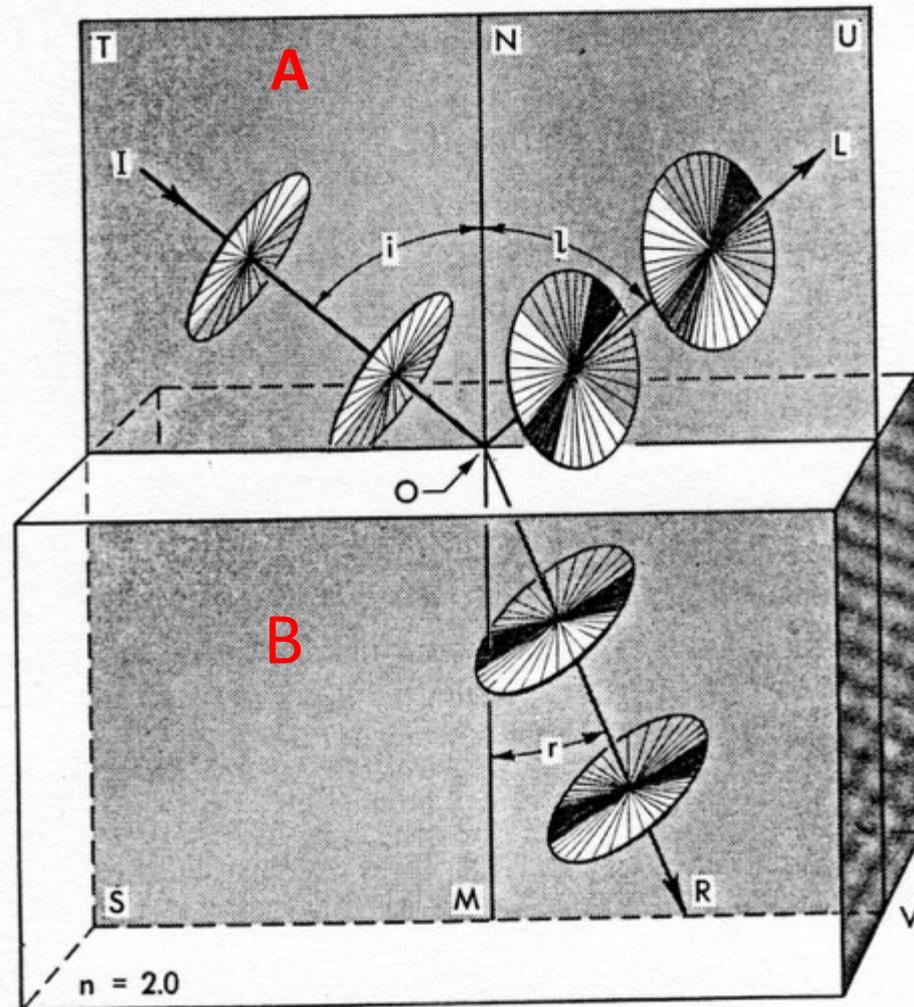


Fig. 2-1. An unpolarized ray, IO , incident in air upon the upper surface of a transparent glass block of index 2.0, forms a reflected ray, OL , and a refracted ray, OR . All the ray paths, as well as the angles of incidence (i), of reflection (l), and of refraction (r), lie within the plane of incidence, $STUV$.

Riflessione e rifrazione dei raggi.

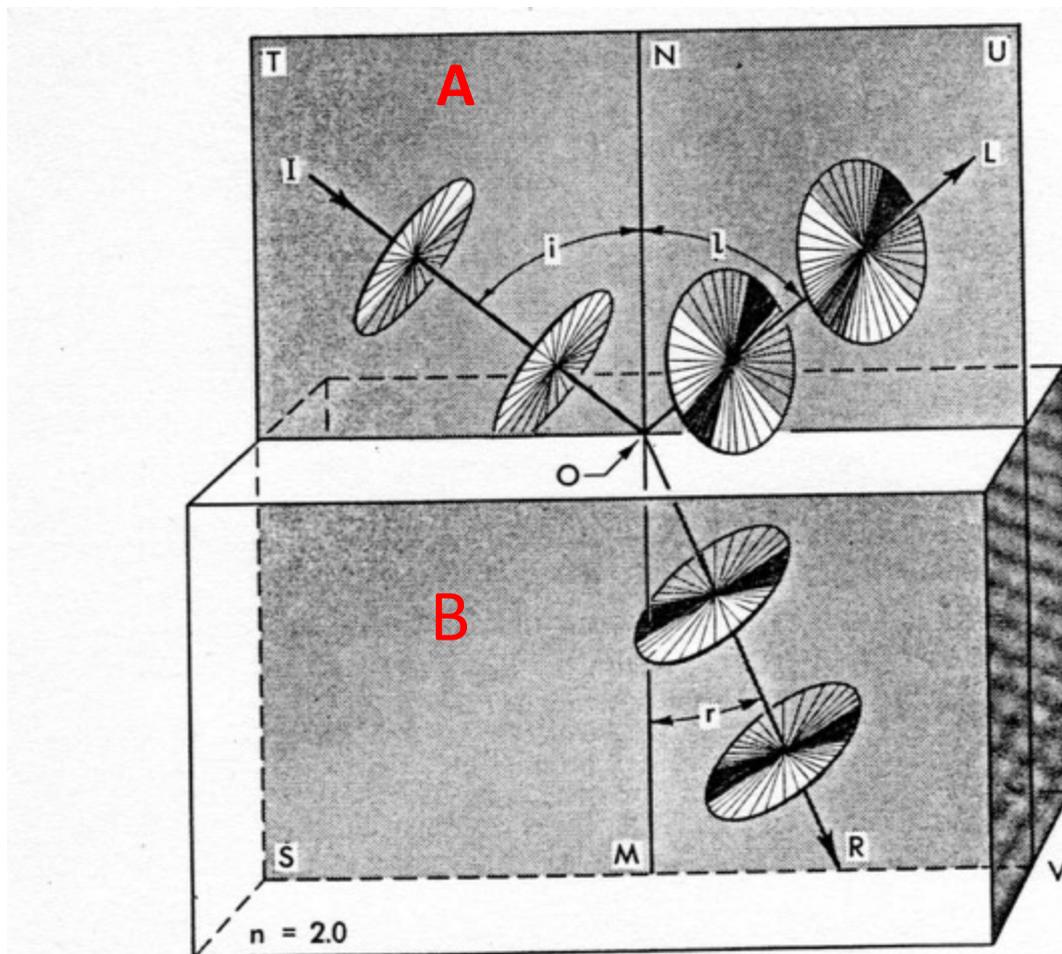


Fig. 2-1. An unpolarized ray, IO , incident in air upon the upper surface of a transparent glass block of index 2.0, forms a reflected ray, OL , and a refracted ray, OR . All the ray paths, as well as the angles of incidence (i), of reflection (l), and of refraction (r), lie within the plane of incidence, $STUV$.

Angolo critico e total riflessione.

Scriviamo la legge di Snell nel seguente modo:

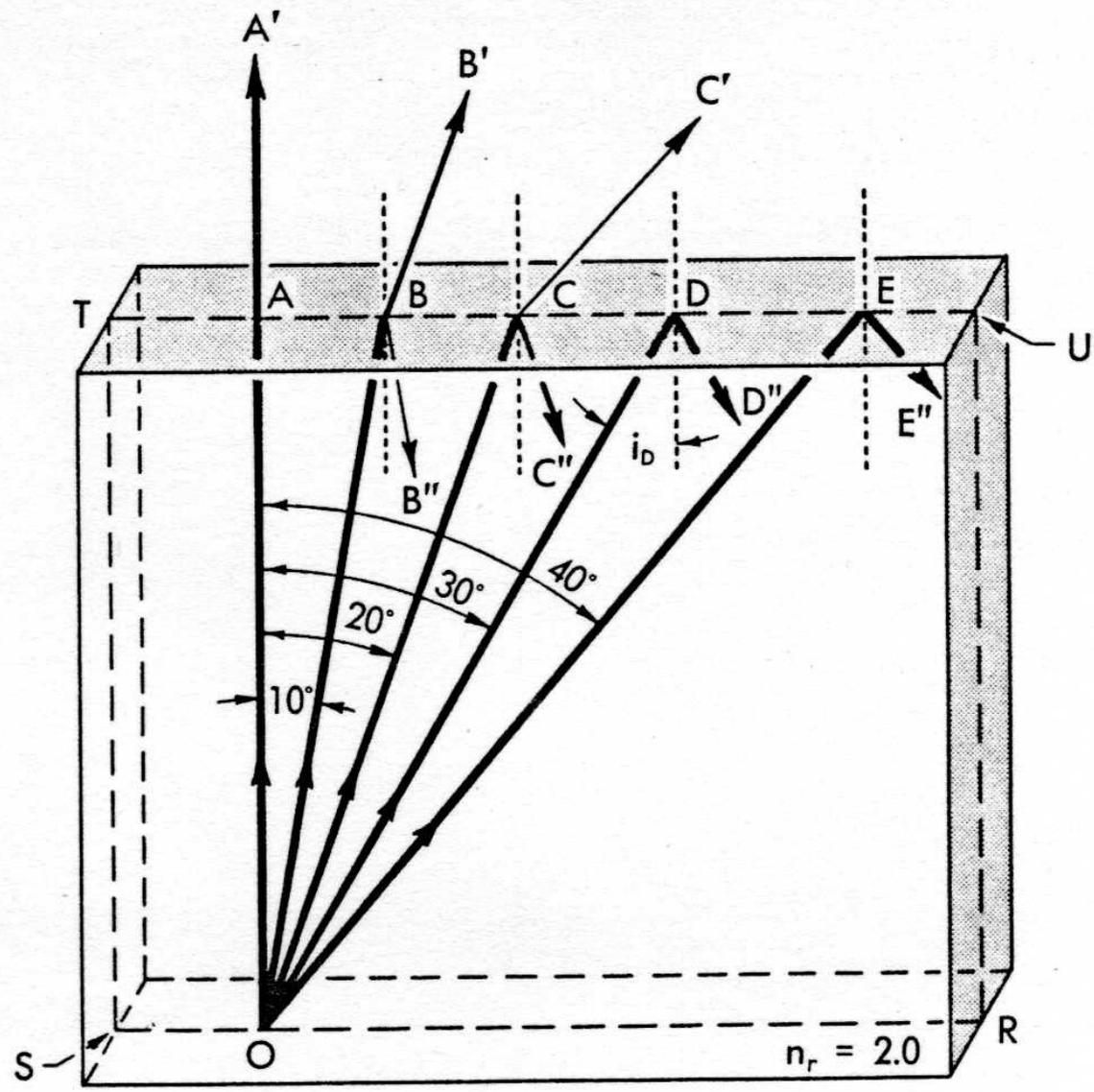
$$\text{sen } r = n_i/n_r * \text{sen } i$$

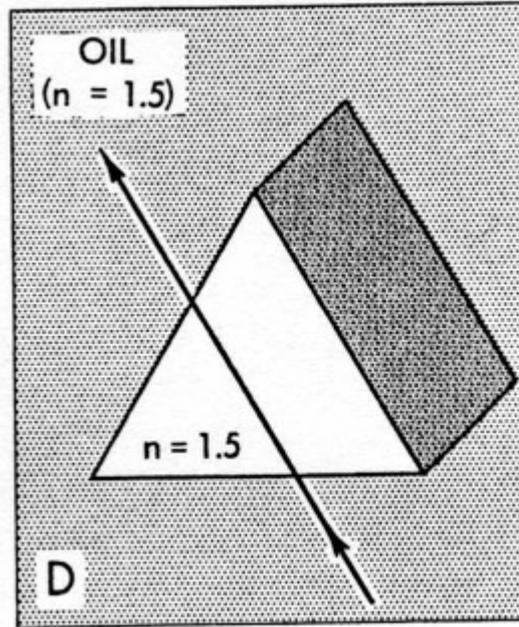
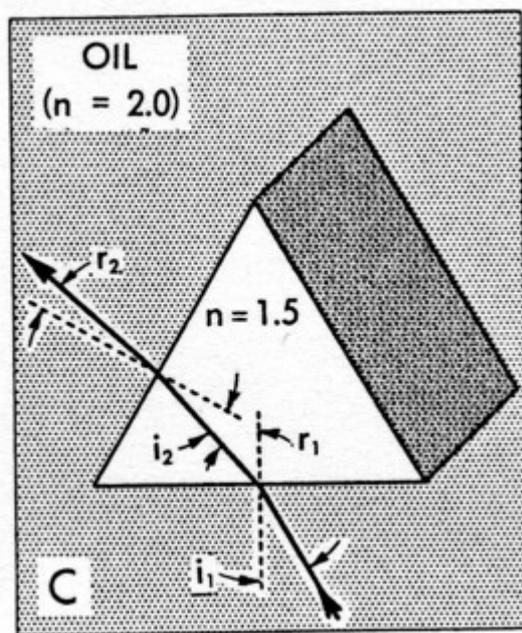
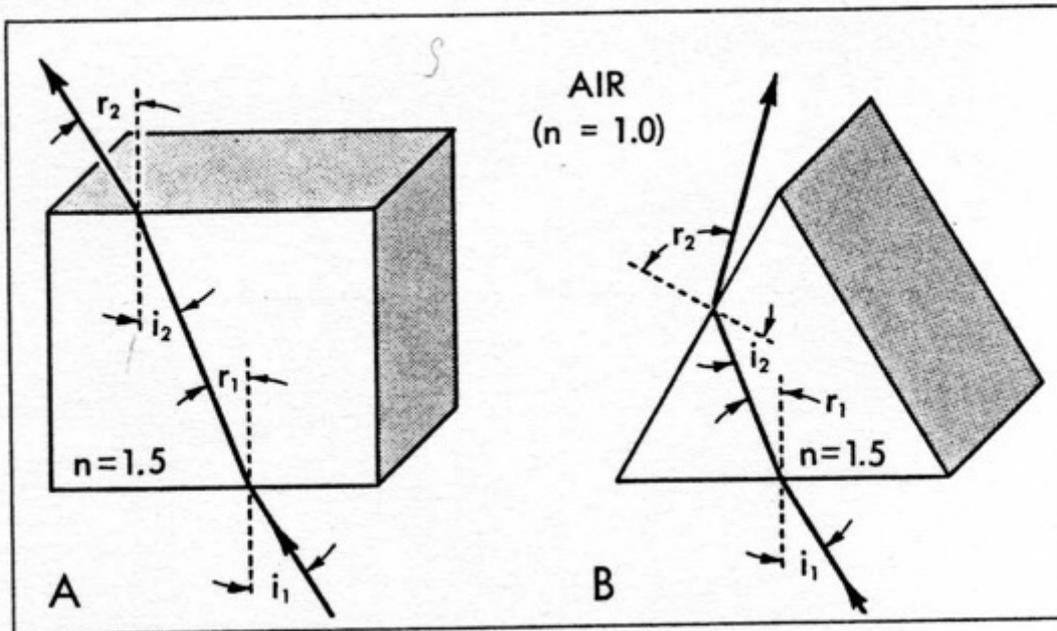
Se il mezzo in cui viaggia il raggio incidente ha indice di rifrazione inferiore al mezzo in cui avviene la rifrazione ($n_i < n_r$) l'angolo di rifrazione si avvicina alla normale di separazione dei due mezzi.

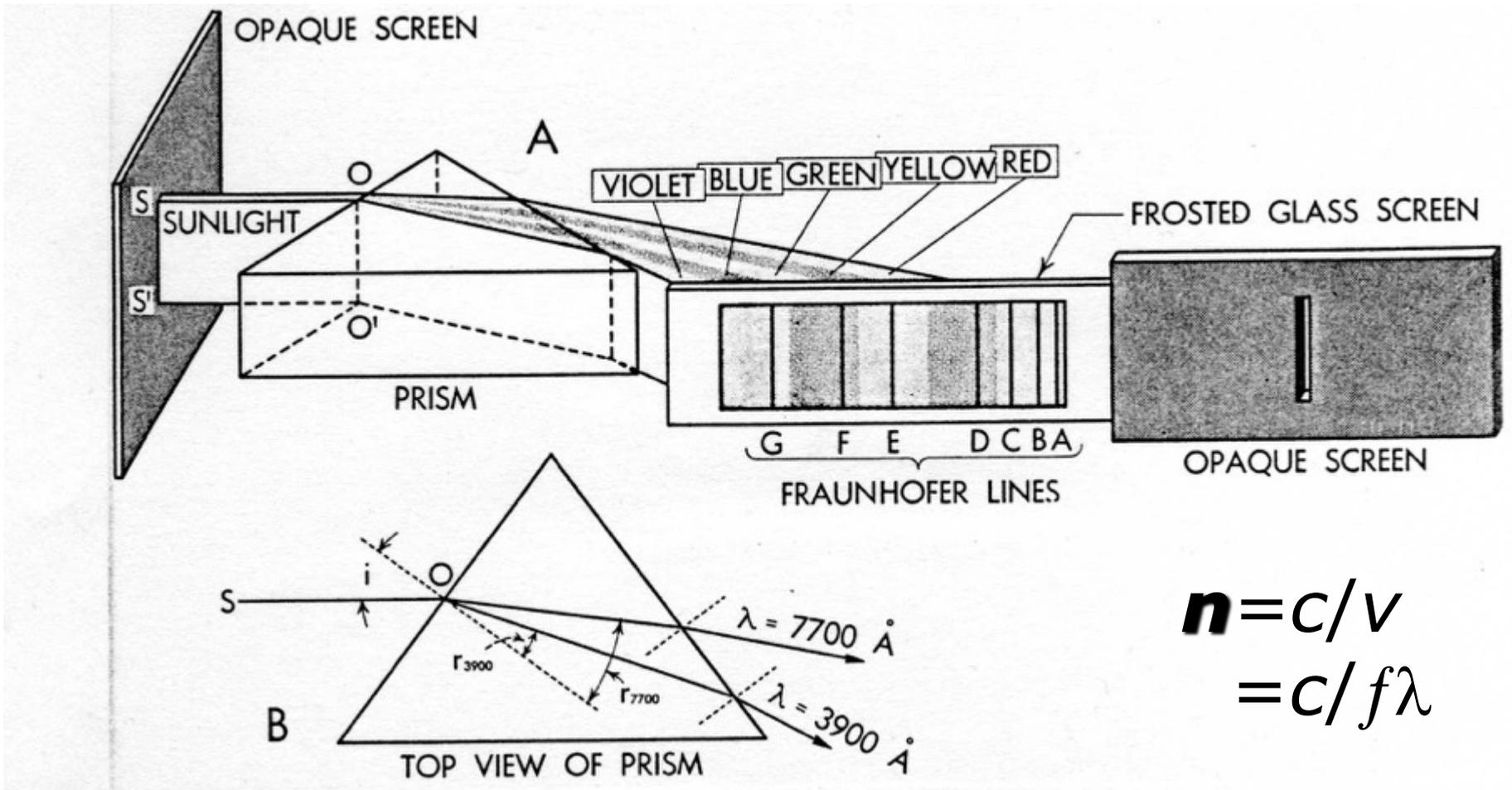
Se il mezzo in cui viaggia il raggio incidente ha indice di rifrazione superiore al mezzo in cui avviene la rifrazione ($n_i > n_r$), il raggio rifratto si allontana dalla normale di separazione dei due mezzi.

Ad esempio se $n_i=2$ e $n_r=1$ per $i=30$ $r=90^\circ$.

Ciò significa che per un angolo pari o superiore a 30 gradi si ha solo riflessione e non più rifrazione.







$$n = c/v$$

$$= c/f\lambda$$

L'indice di rifrazione del vetro dipende dal colore della luce e quindi dalla lunghezza d'onda della luce. I raggi luminosi di colori diversi sono deviati verso il basso con angoli diversi. Quanto maggiore è l'indice di rifrazione per un dato colore, tanto maggiore è l'angolo di deviazione.

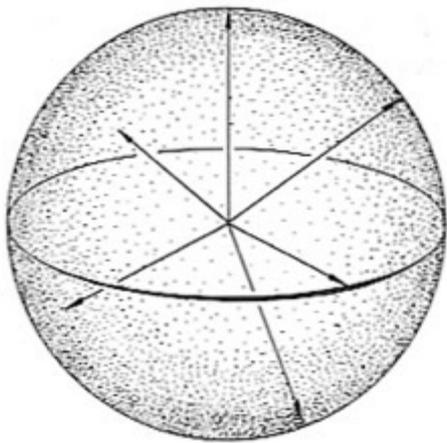
Isotropia e Anisotropia

I minerali monometrici, il vetro, i liquidi e i gas hanno un valore dell'indice di rifrazione unico, indipendentemente dall'orientazione dei raggi luminosi. Tali sostanze sono dette **ISOTROPE**.

Gli indici di rifrazione possono variare in tutti i minerali (eccetto in quelli del gruppo monometrico) a seconda dell'orientazione del raggio luminoso. Si dice che questi minerali sono **ANISOTROPI**.

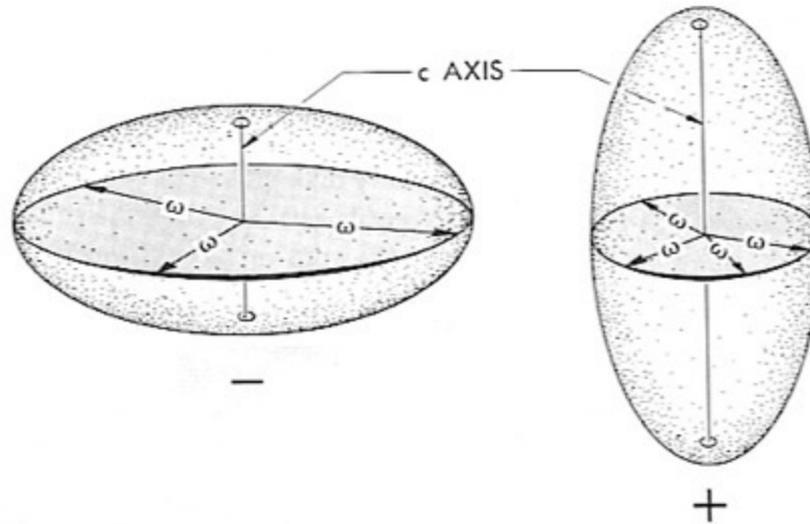
Indicatrici Ottiche

- Mappa 3-d degli indici di rifrazione per varie direzioni di vibrazione del raggio luminoso.
- L'orientazione dell'indicatrice ottica entro un minerale è simmetrica con gli assi cristallografici.



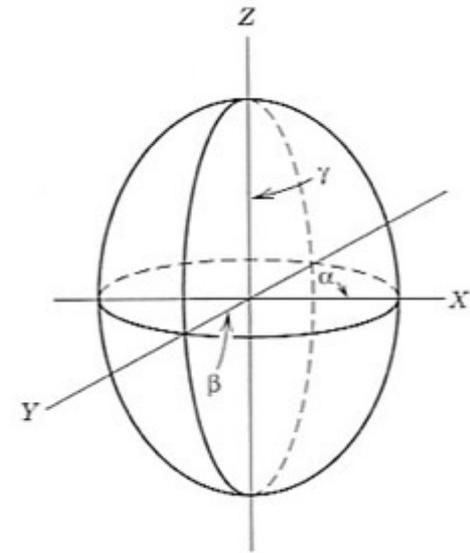
Isotropo

Monometrico



Anisotropo – Uniassico

**Tetragonale
Trigonale Esagonale**



**Anisotropo -
Biassico**

**Ortorombico
Monoclino
Triclino**

Indicatrici Ottiche

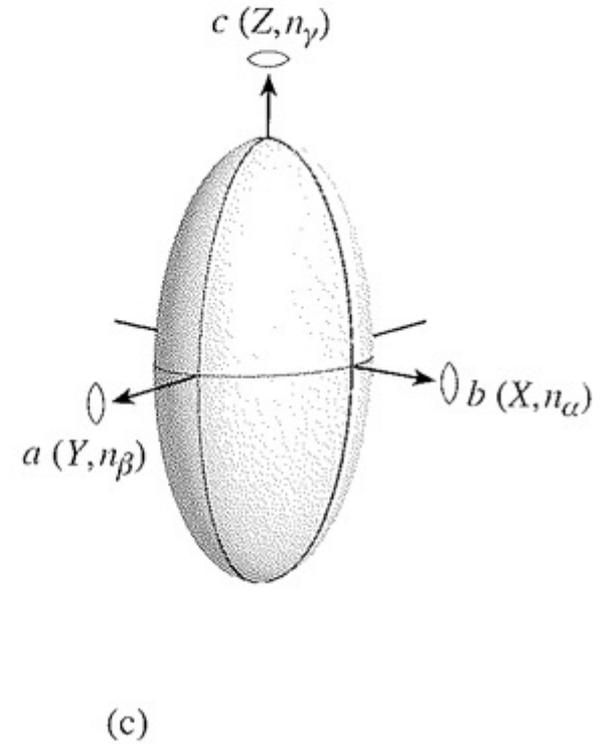
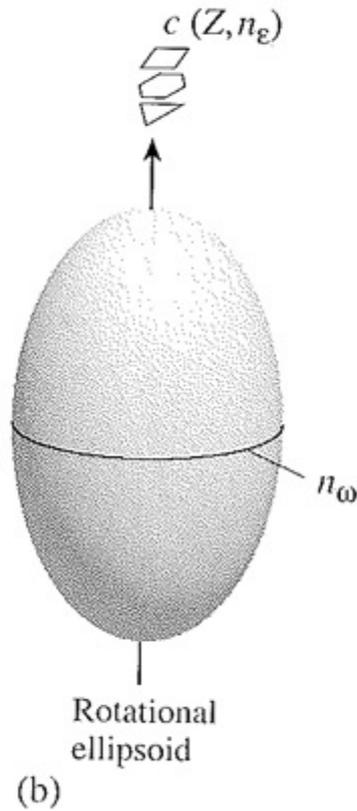
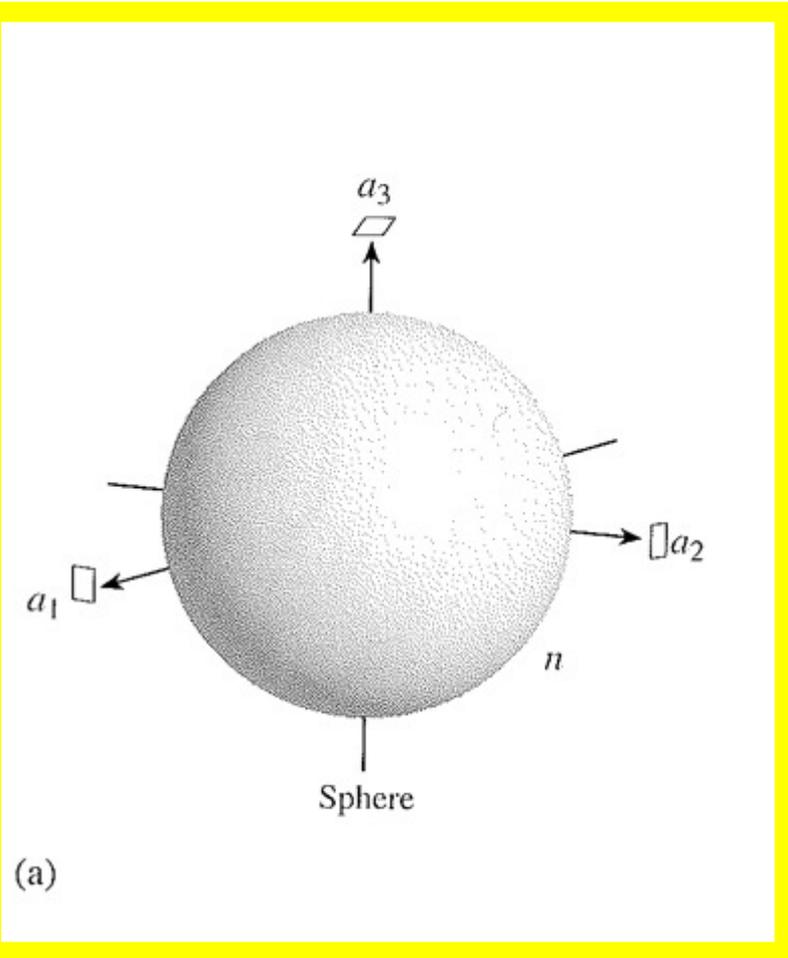
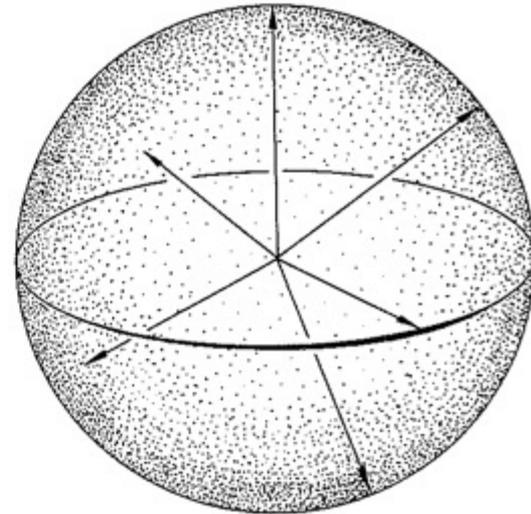


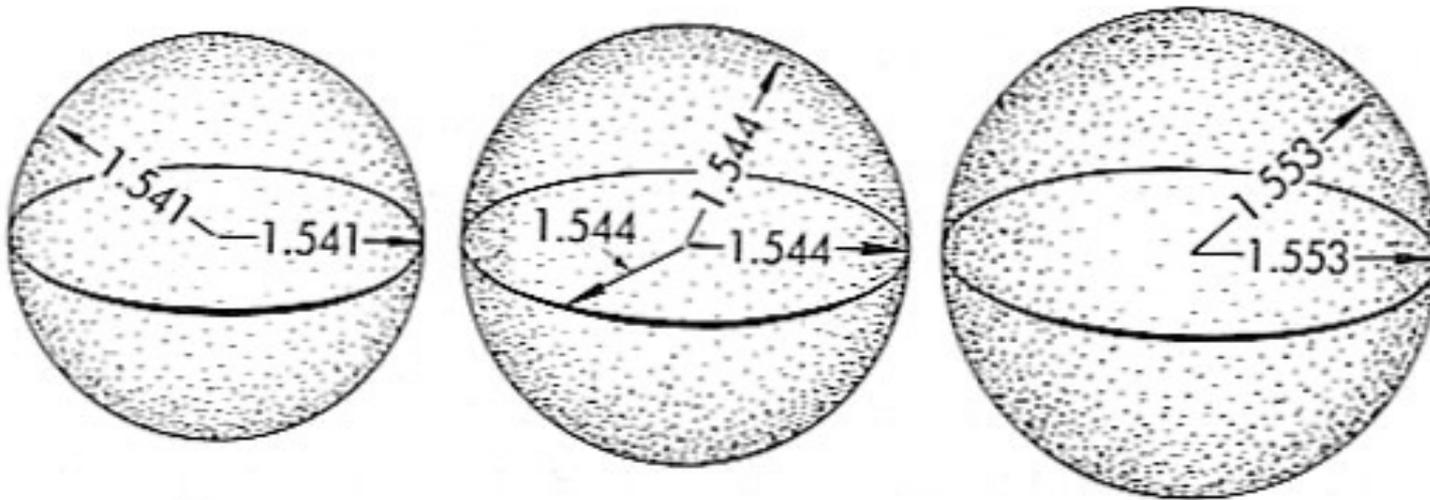
Fig. 6-3. Isotropic indicatrix of a crystal for sodium light. The crystal's refractive index for sodium light (n_D) remains constant regardless of the direction in which the light is vibrating; the indicatrix is therefore a sphere.



THE ISOTROPIC INDICATRIX

Indicatrice Isotropa

Una sfera il cui raggio corrisponde all'indice di rifrazione - ***n***



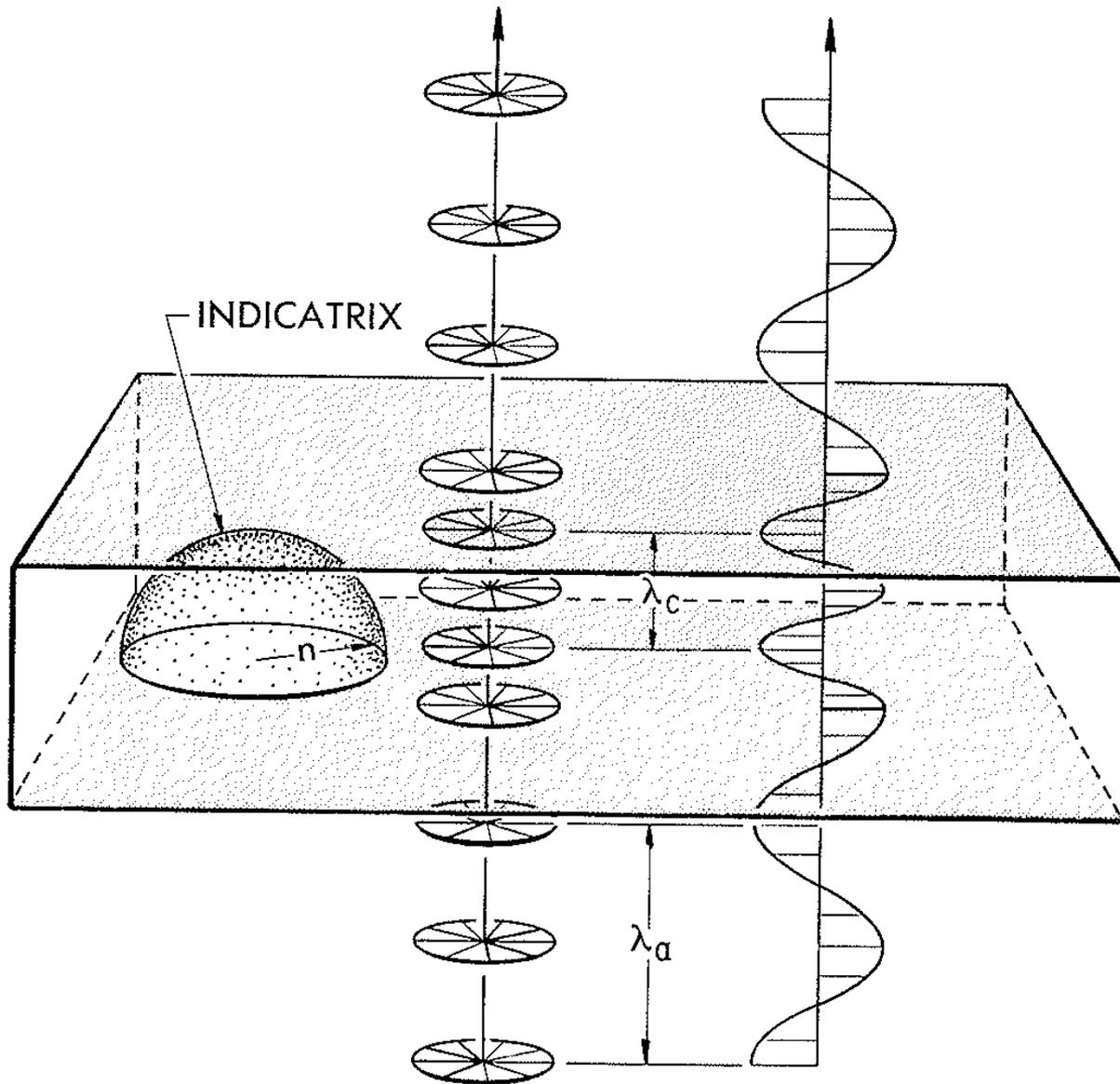
λ_c 6563Å Red

λ_D 5893Å Yellow

λ_F 4861Å Blue

$$\mathbf{n} = c/v$$
$$= c/f\lambda$$

Le tre sfere rappresentano i valori di ***n*** per diverse lunghezze d'onda della luce nello stesso minerale.



$$\lambda = c / fn$$

$$\lambda_a > \lambda_c$$

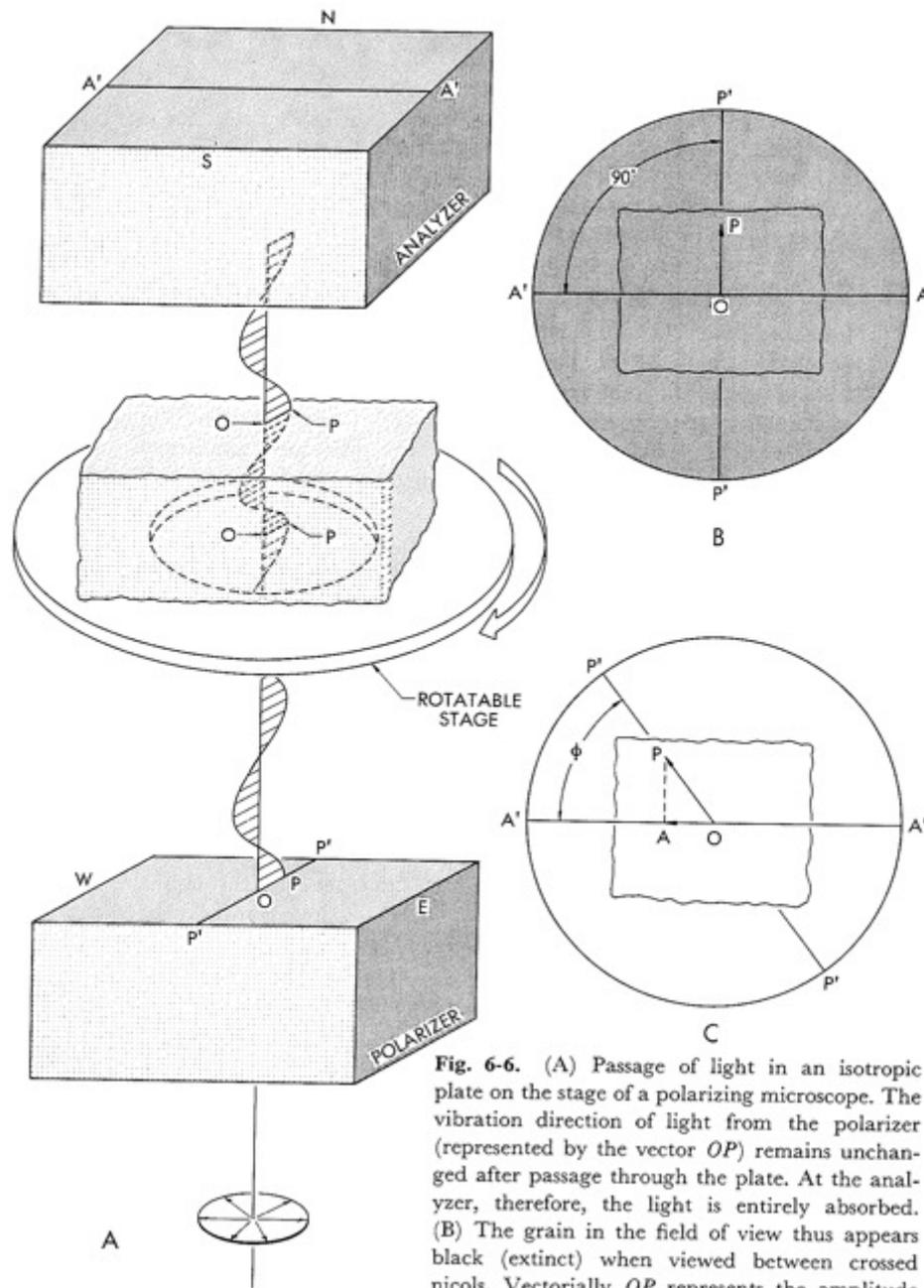
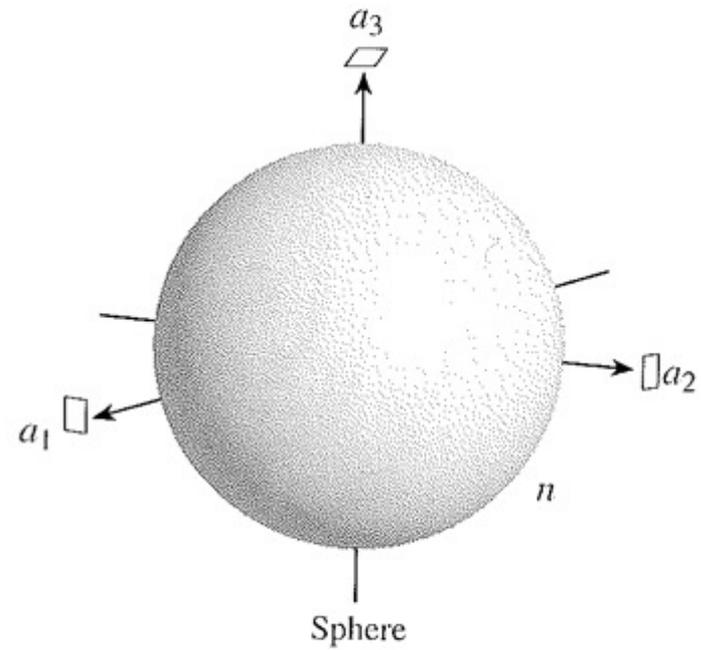
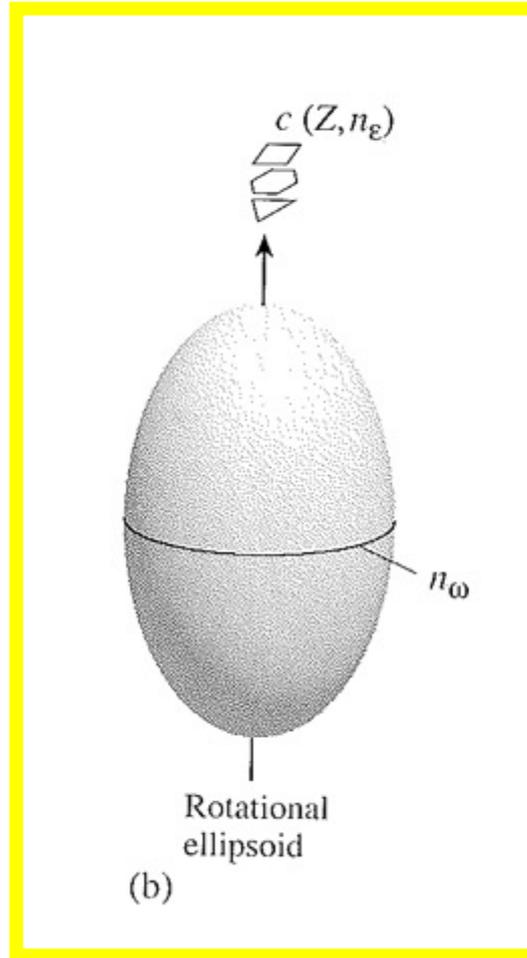


Fig. 6-6. (A) Passage of light in an isotropic plate on the stage of a polarizing microscope. The vibration direction of light from the polarizer (represented by the vector OP) remains unchanged after passage through the plate. At the analyzer, therefore, the light is entirely absorbed. (B) The grain in the field of view thus appears black (extinct) when viewed between crossed nicols. Vectorially OP represents the amplitude

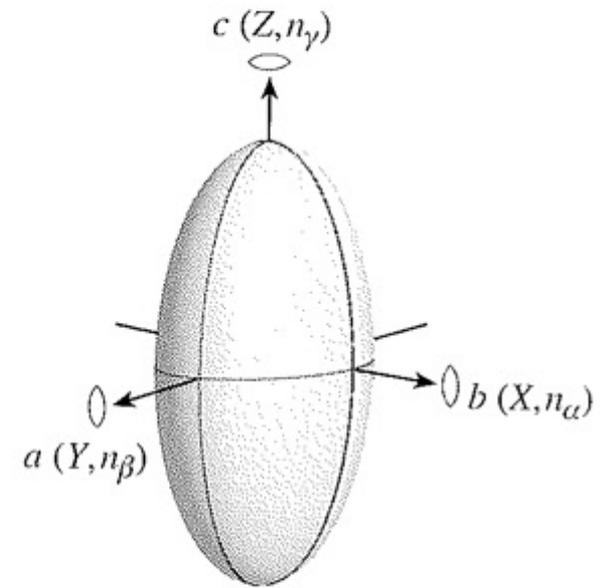
Indicatrici Ottiche



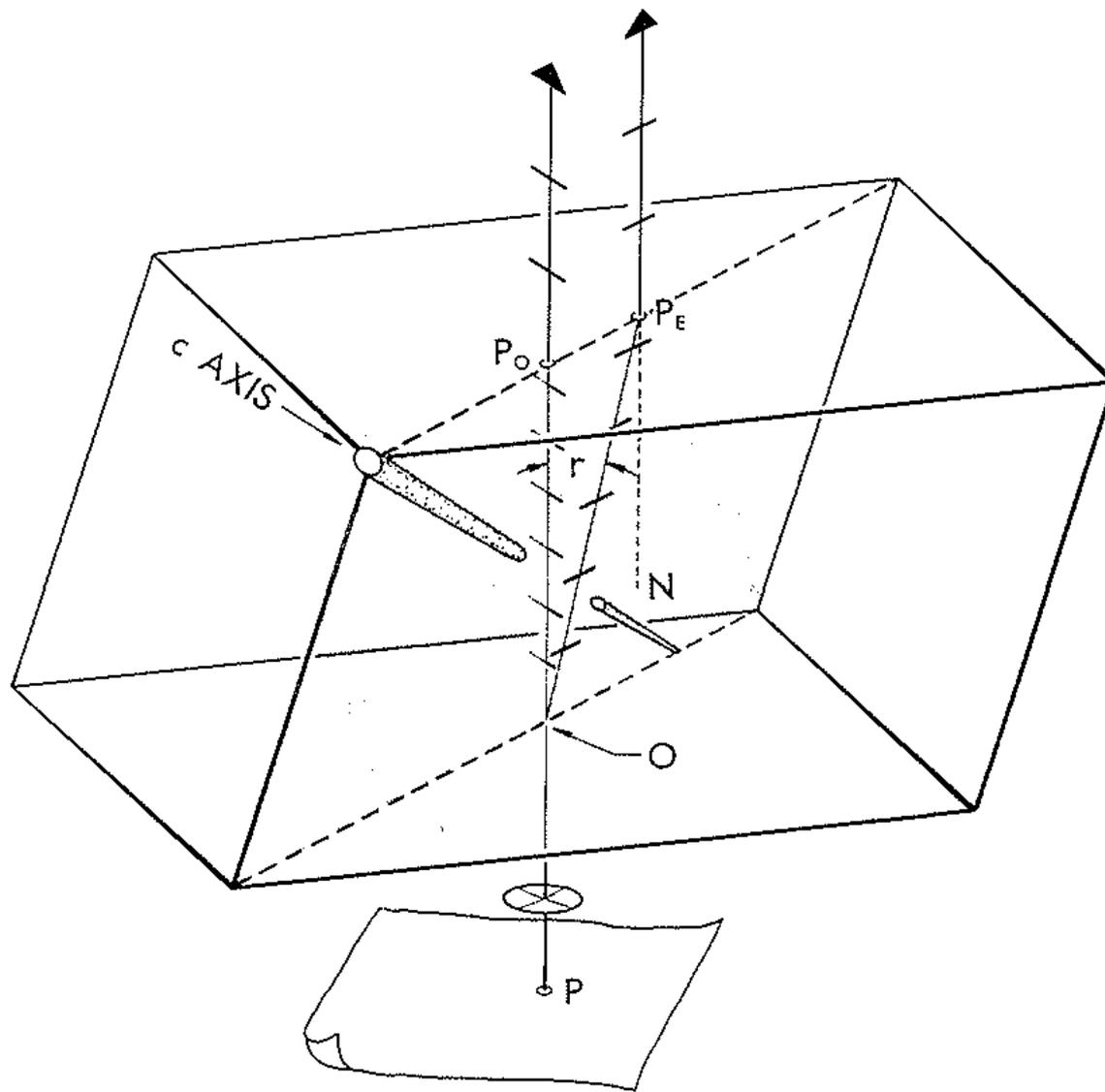
(a)



(b)

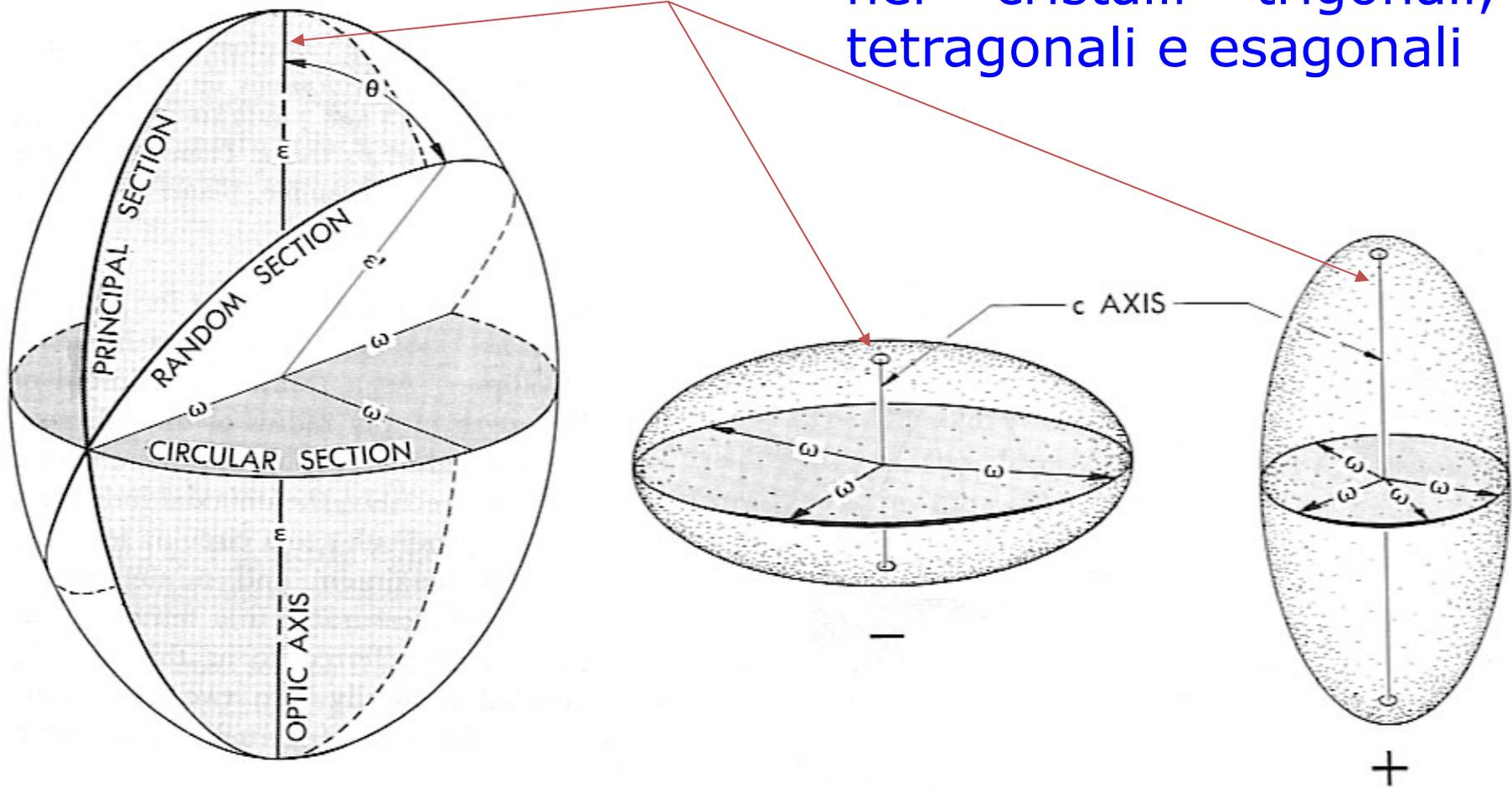


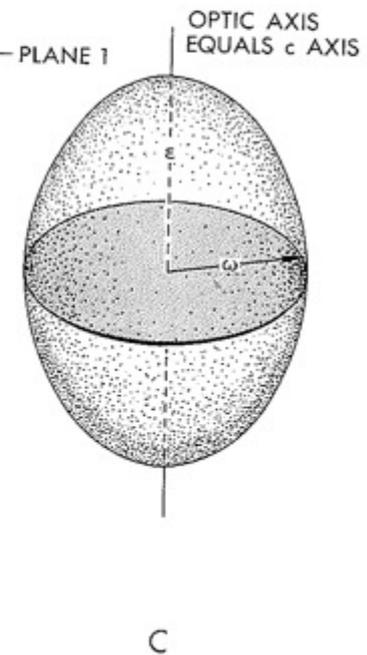
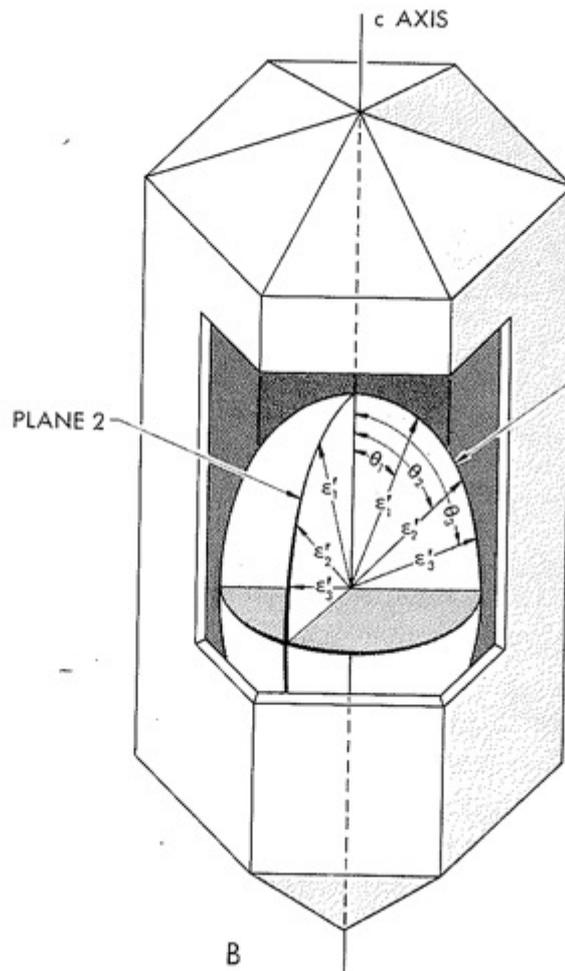
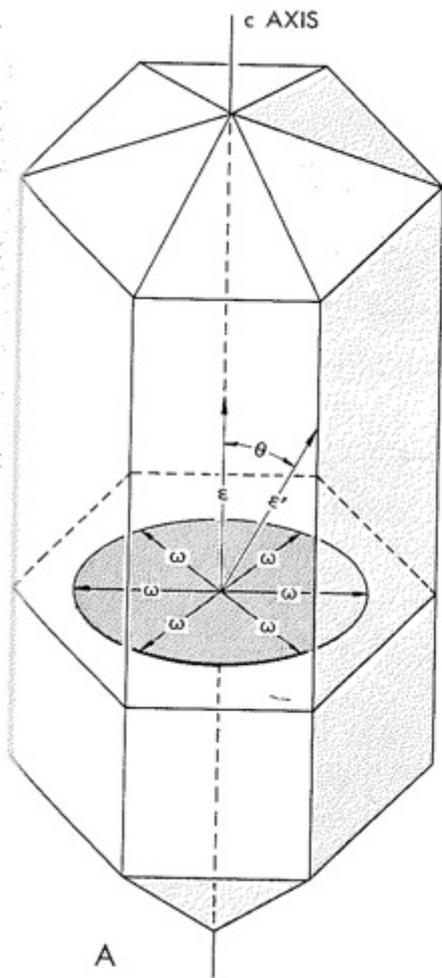
(c)

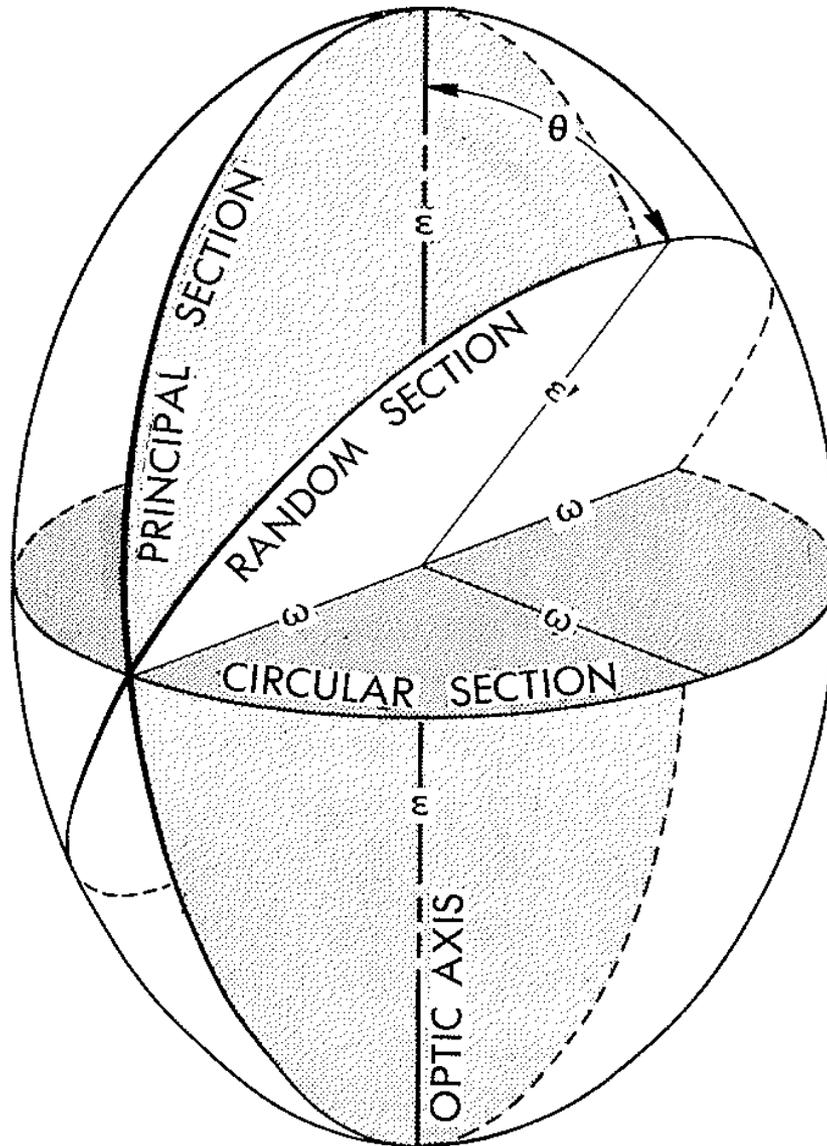


Uniaxial Indicatrix

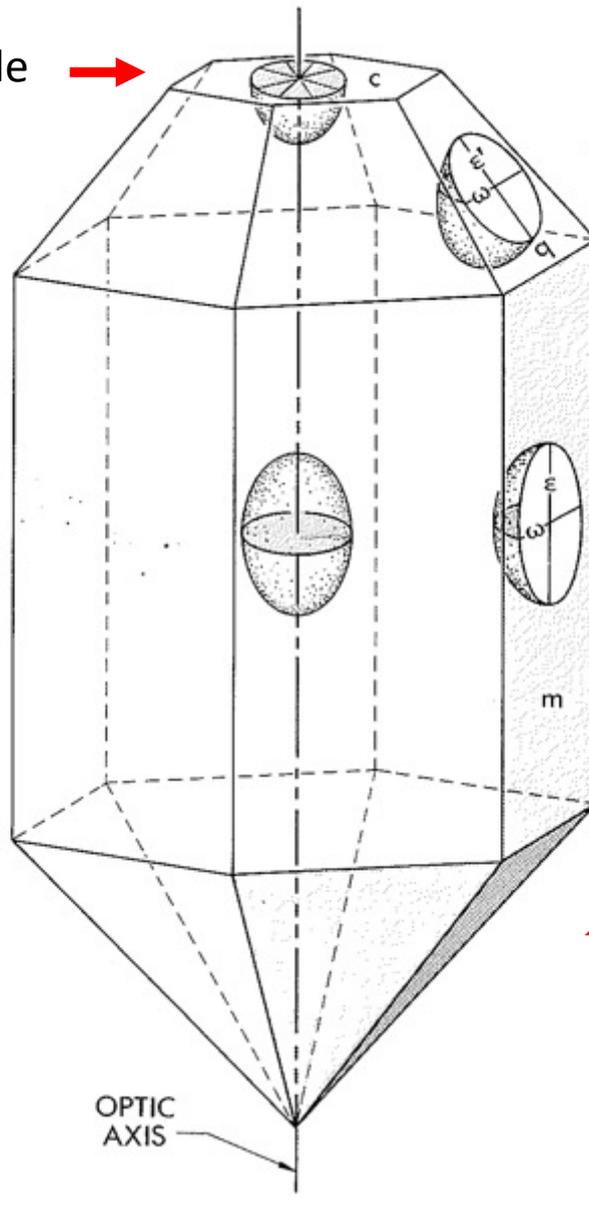
Asse Ottico = l'asse C
nei cristalli trigonali,
tetragonali e esagonali

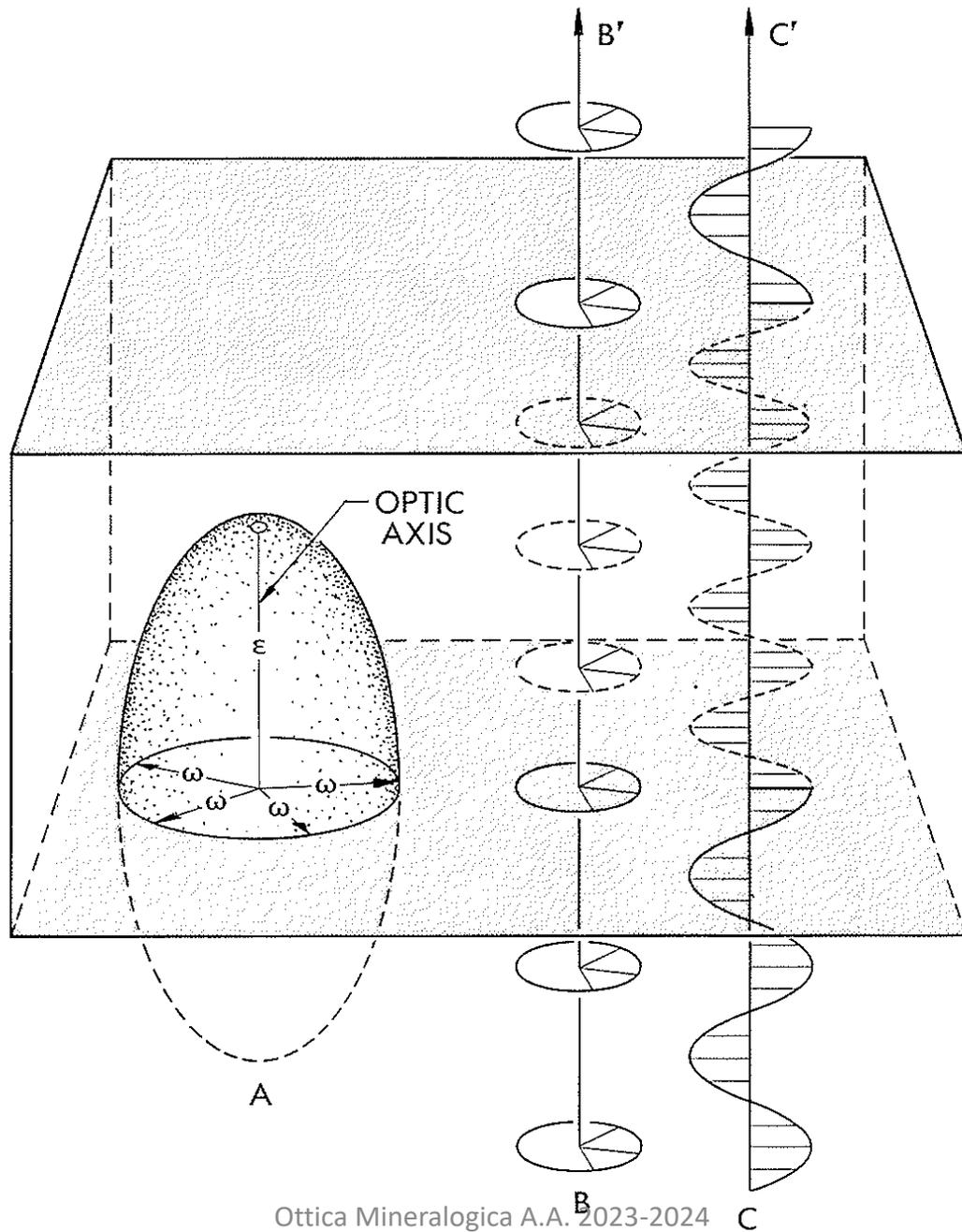


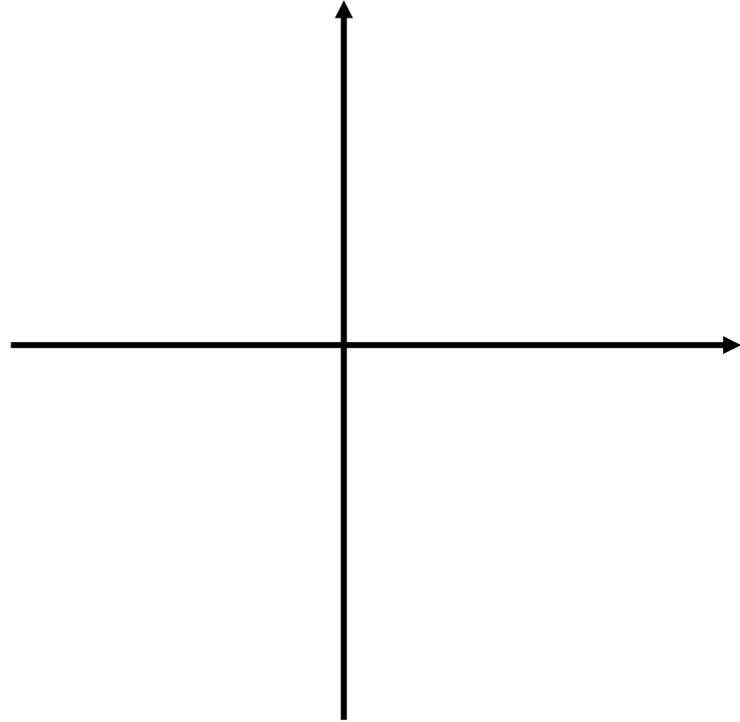
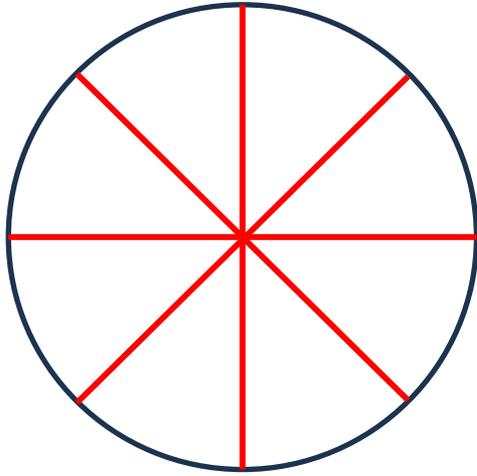


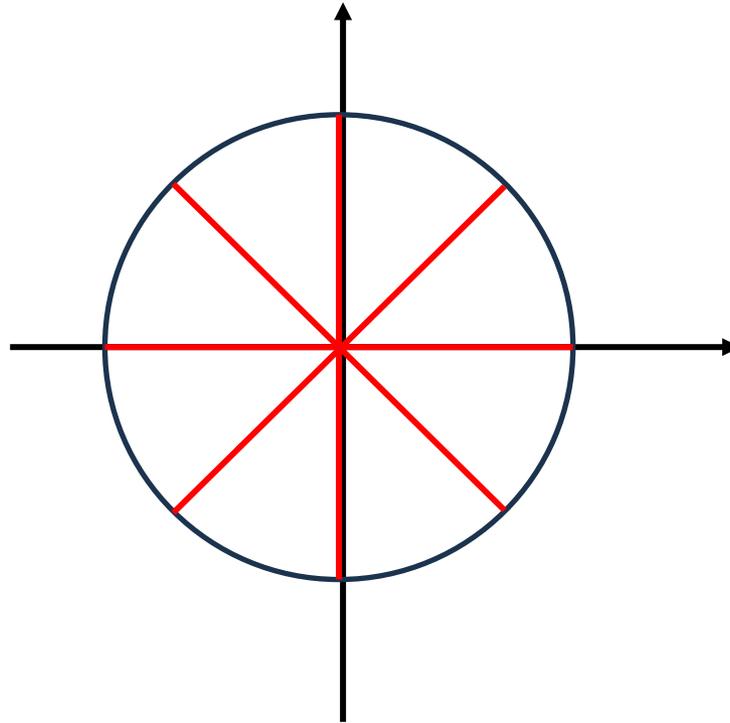


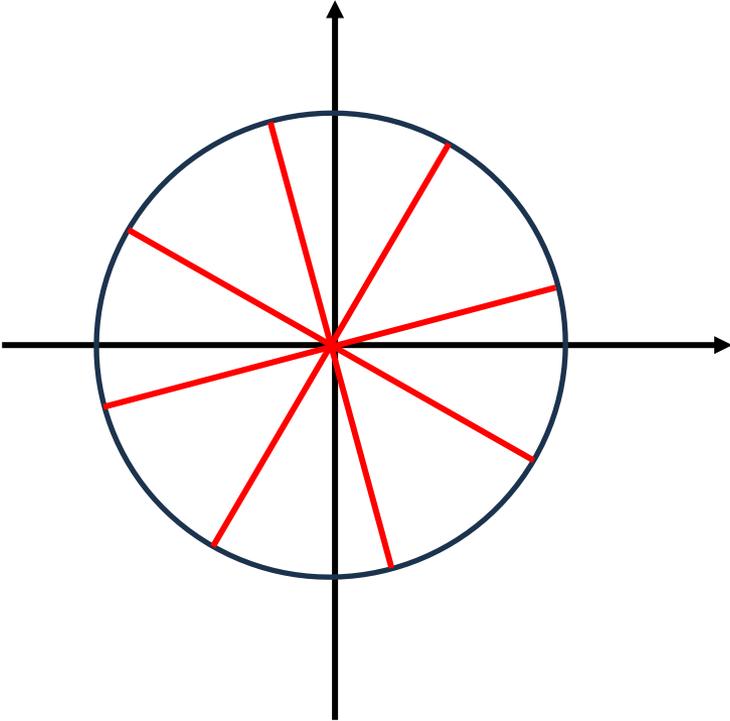
Superficie sezione sottile →

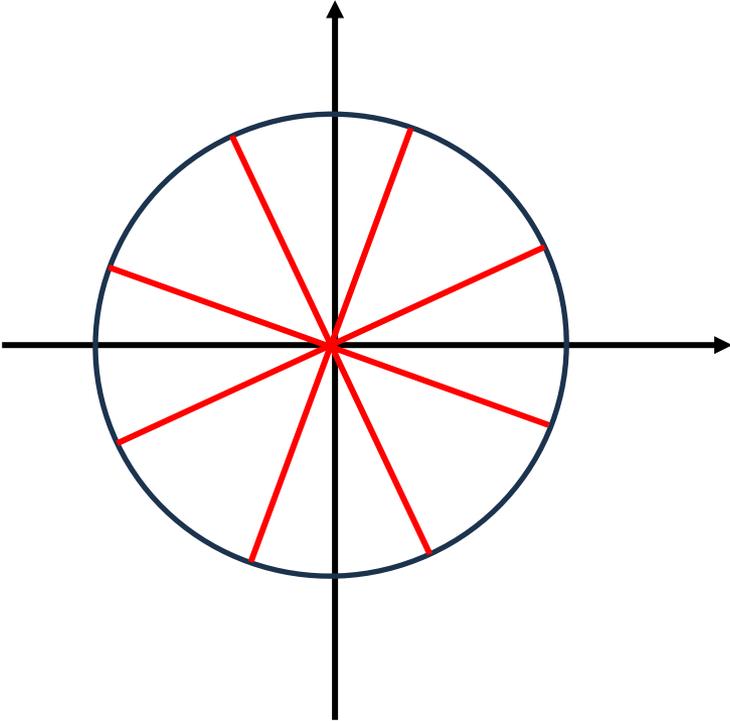












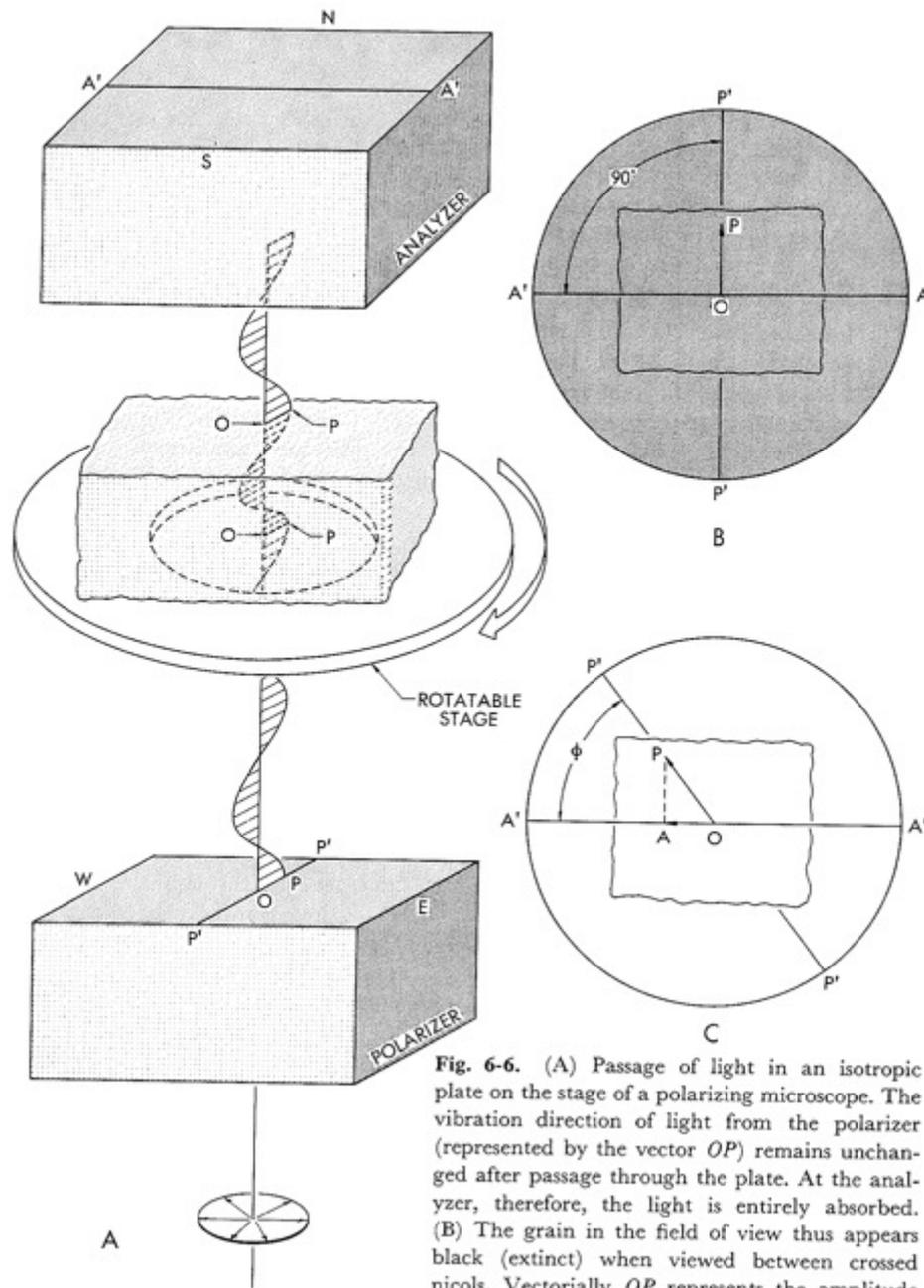
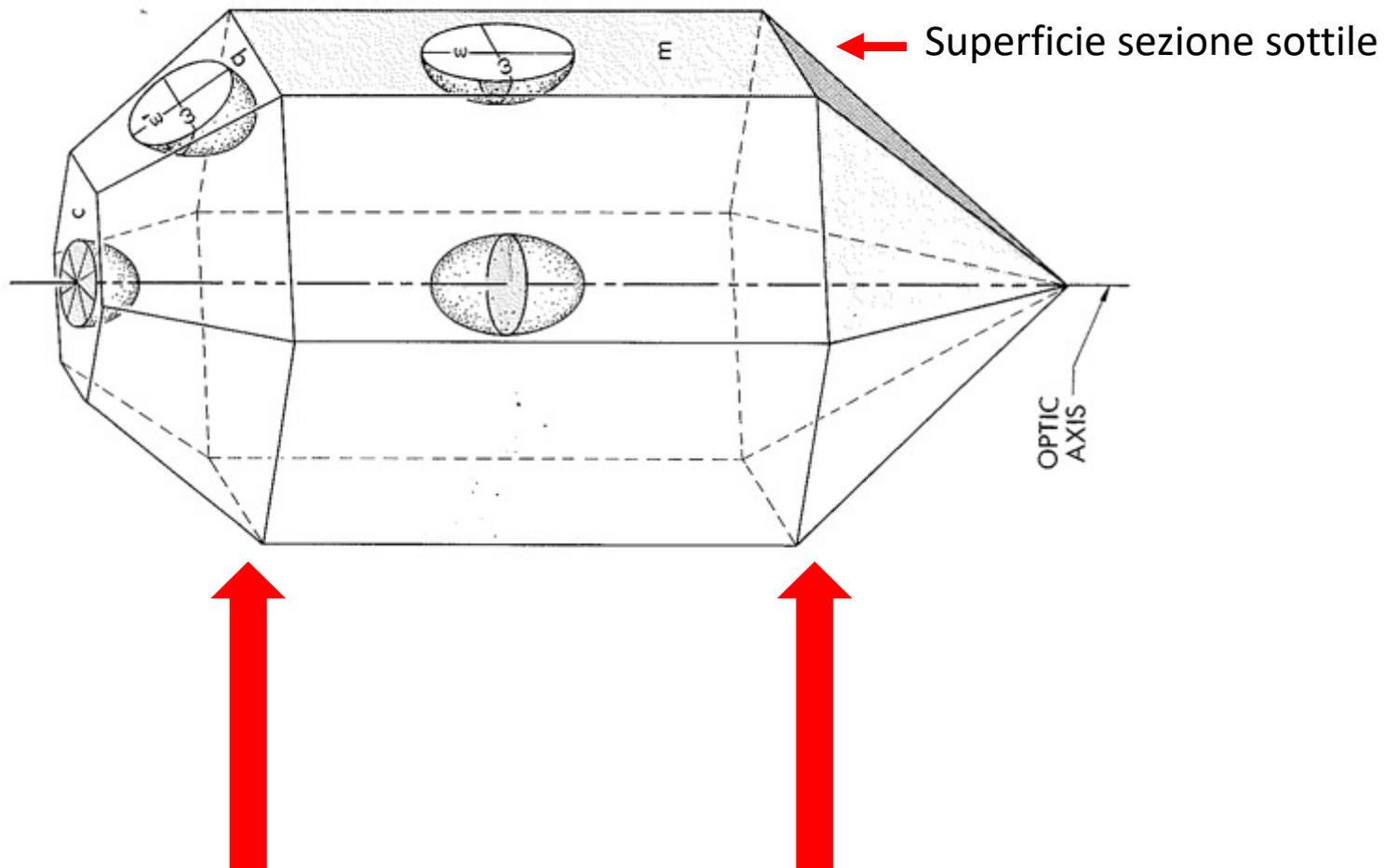
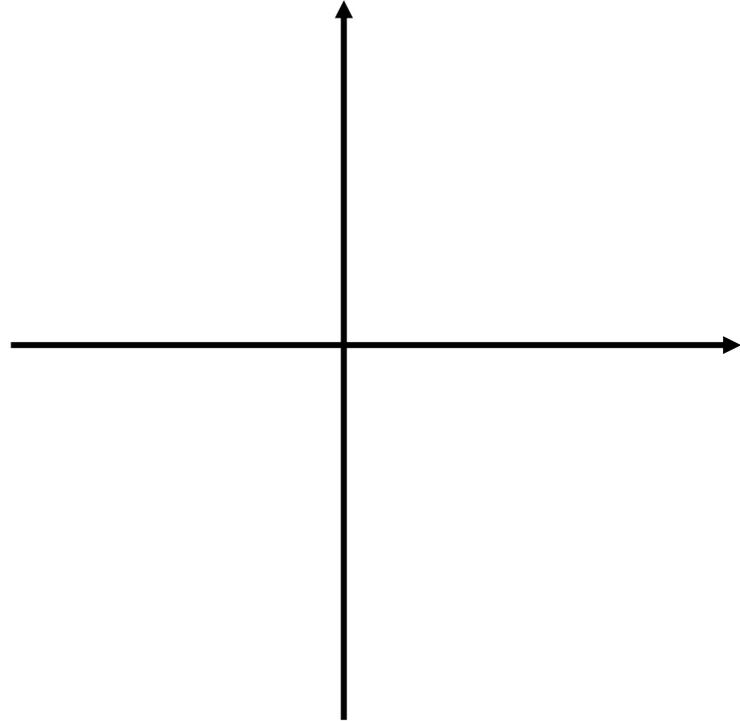
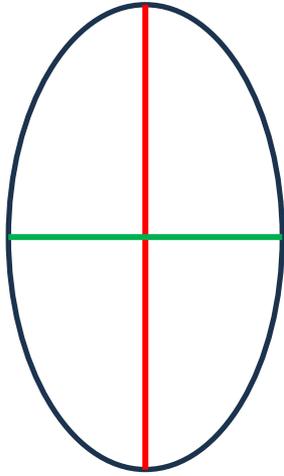
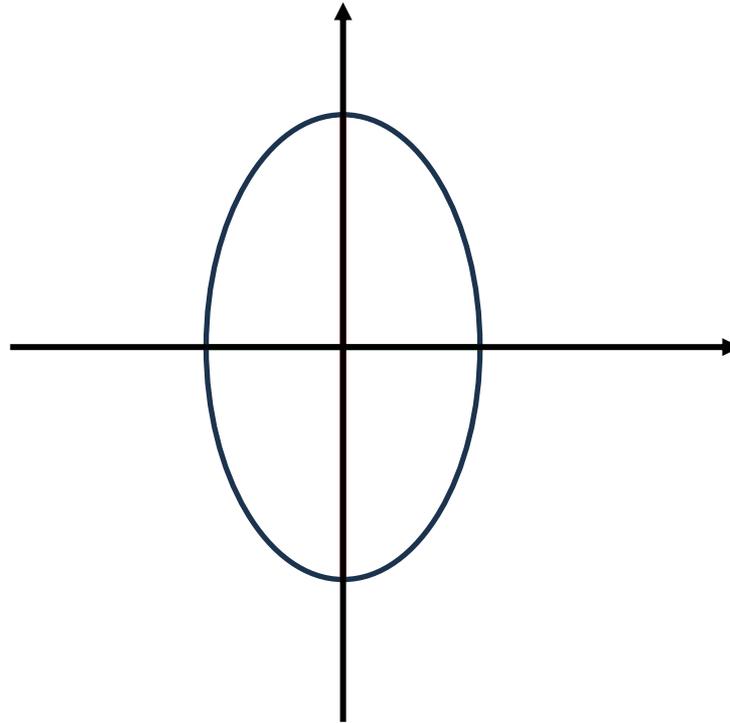
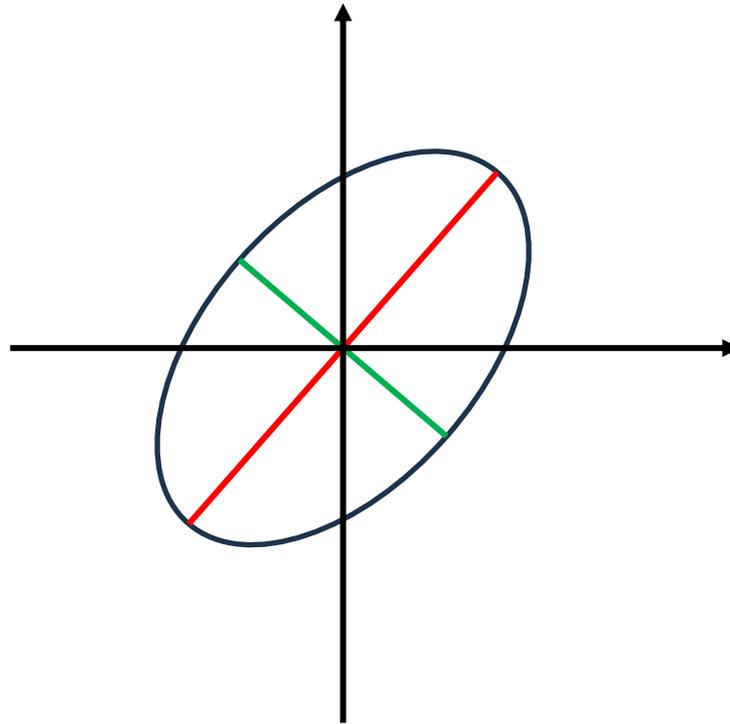


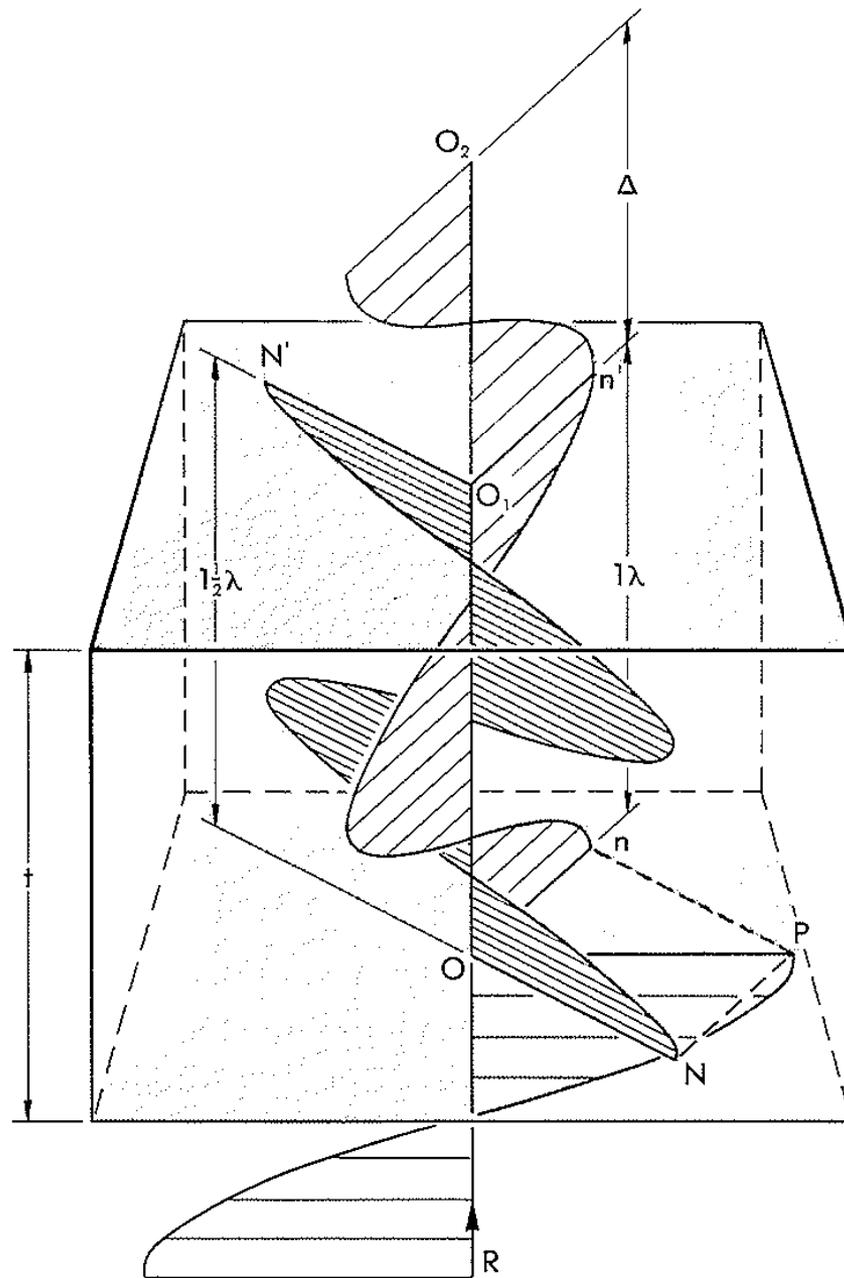
Fig. 6-6. (A) Passage of light in an isotropic plate on the stage of a polarizing microscope. The vibration direction of light from the polarizer (represented by the vector OP) remains unchanged after passage through the plate. At the analyzer, therefore, the light is entirely absorbed. (B) The grain in the field of view thus appears black (extinct) when viewed between crossed nicols. Vectorially OP represents the amplitude



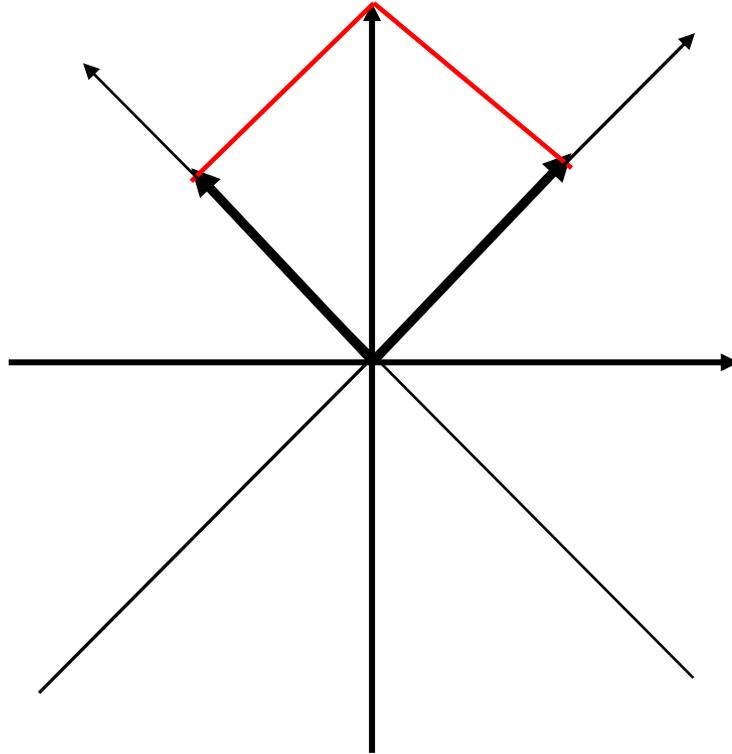




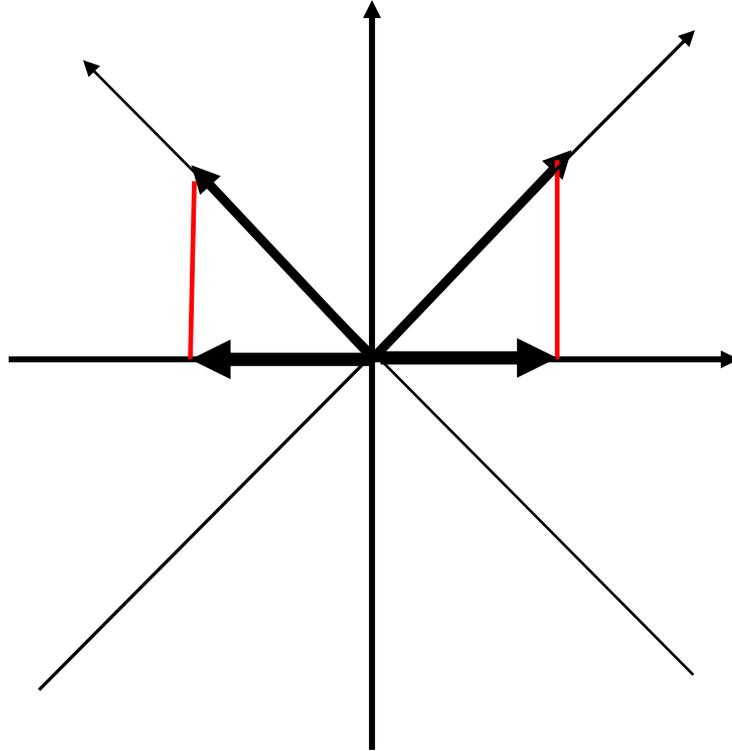


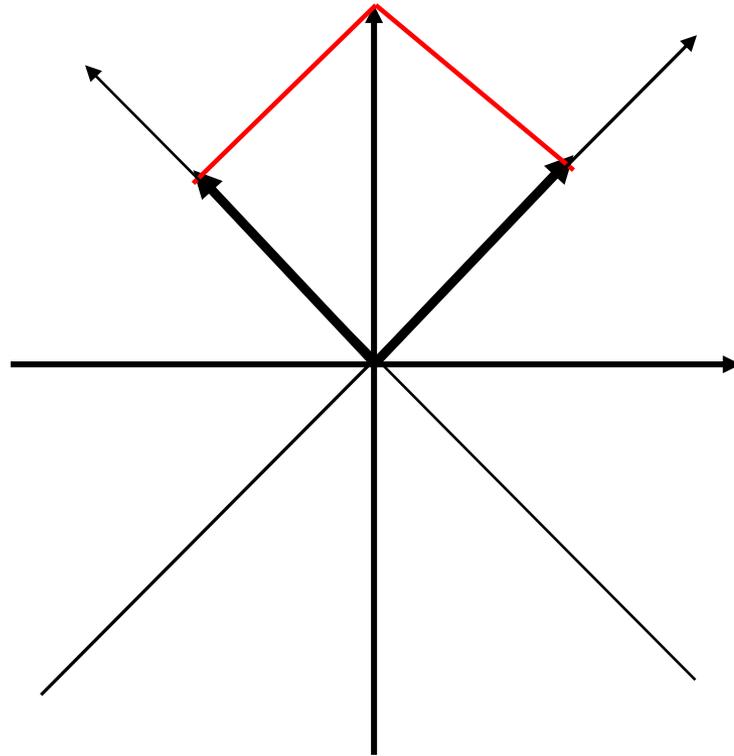


Considero una luce monocromatica, ossia con un'unica λ

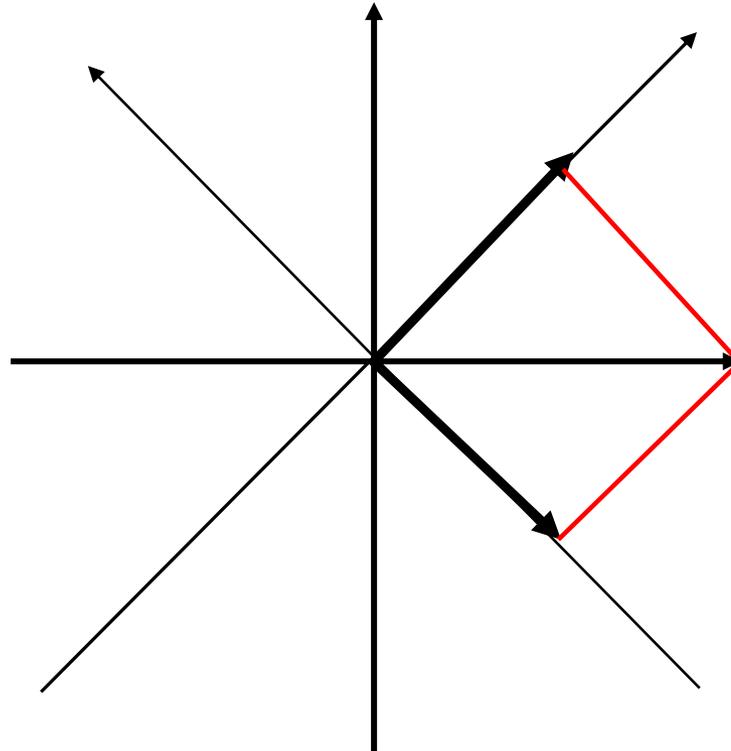


Ritardo pari a λ o a un numero pari di λ
si ha estinzione





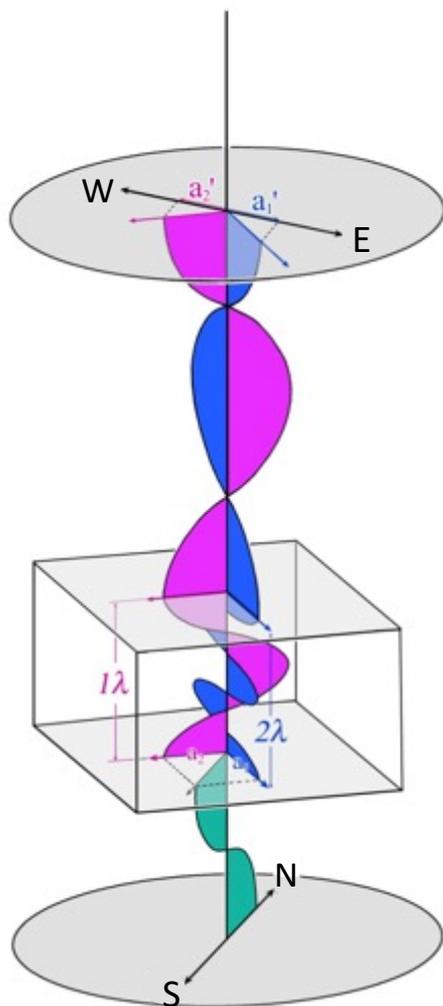
Ritardo pari a $\lambda/2$ o a un numero dispari di $\lambda/2$
appare il colore



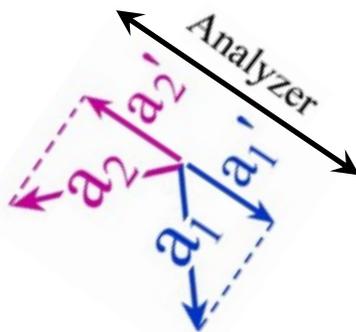
COLORI D'INTERFERENZA - MINERALI BIRIFRANGENTI

Passaggio della luce (per semplicità solo monocromatica) attraverso un minerale anisotropo orientato a 45° rispetto alla direzione dei polarizzatori

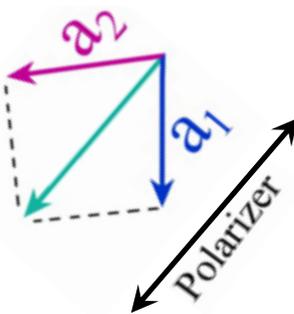
A



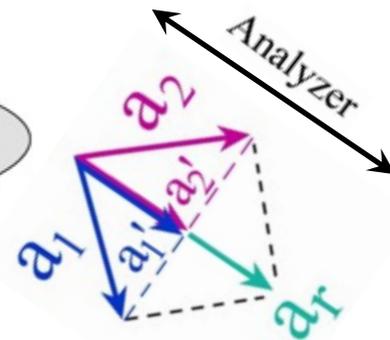
Destructive interference



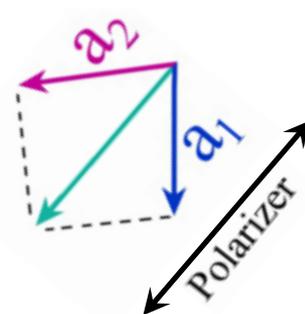
Double refraction



Constructive interference



Double refraction



Onda viola veloce associata all'indice n piccolo

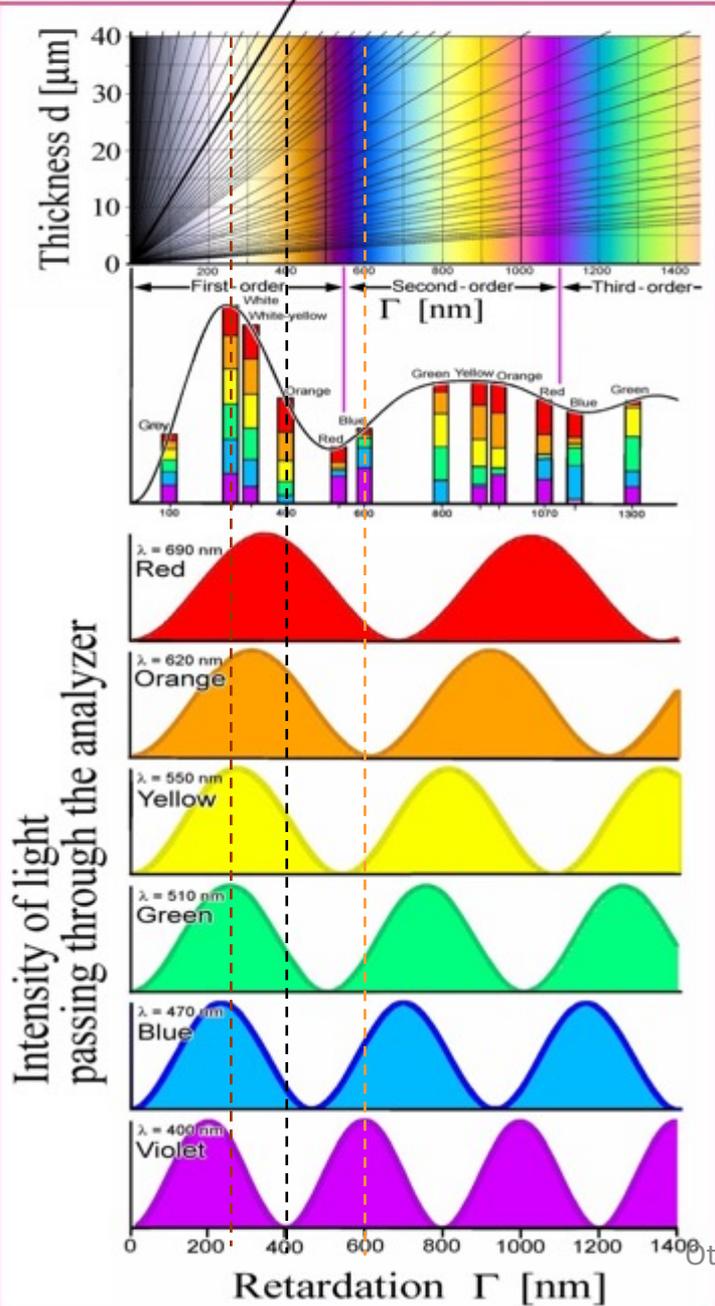
Onda blu lenta associata all'indice n grande

A: interferenza distruttiva – il ritardo tra le 2 onde accumulato nel cristallo è pari a λ (o un n° pari di λ)

B: interferenza costruttiva – il ritardo tra le 2 onde accumulato nel cristallo è pari a $\lambda/2$ (o un n° dispari di $\lambda/2$)

Interference colour sequence

Birifrangenza = $\Delta n = (n_z - n_x)$



COLORI D'INTERFERENZA

Tavola di Michel-Lévy :

relazione tra :

- spessore lamina (d),
- birifrangenza dei minerali (linee) = $n_1 - n_2$
- Ritardo $R = d * (n_1 - n_2)$

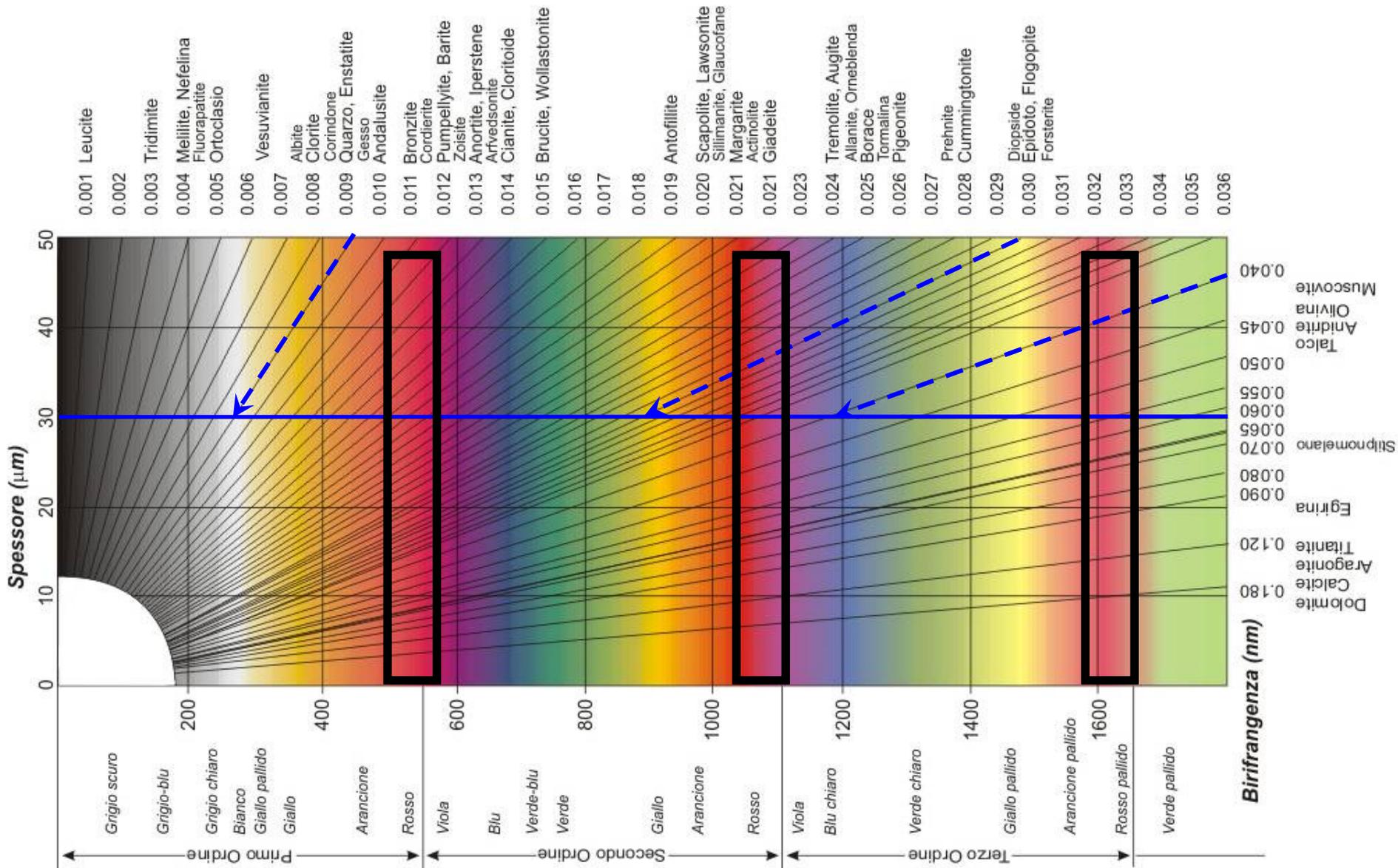
Il colore d'interferenza, per uno specifico R, deriva dalla somma di tutte le intensità delle lunghezze d'onda dello spettro visibile, modificate per interferenza nell'analizzatore.

Uno specifico colore d'interferenza, caratterizzato da una precisa composizione spettrale, compare una volta sola nella carta dei colori.

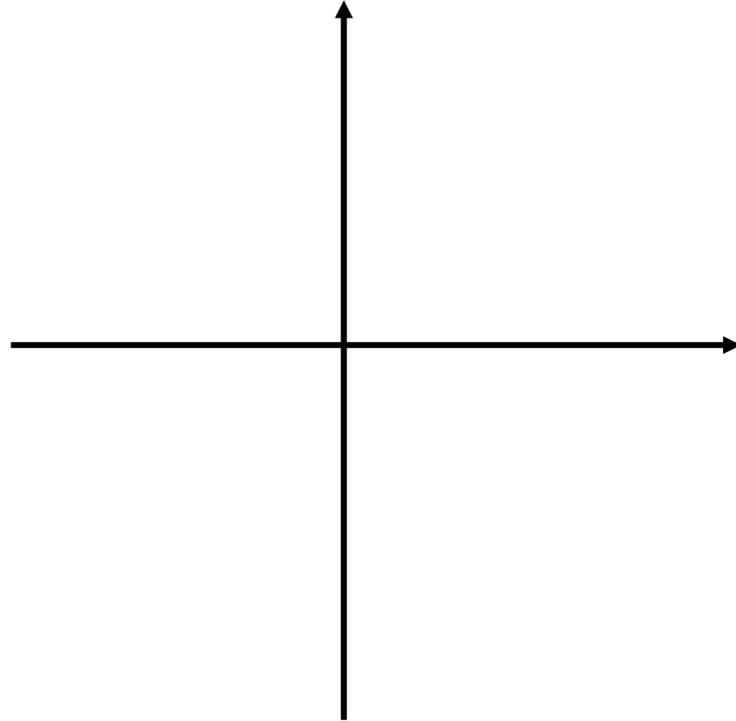
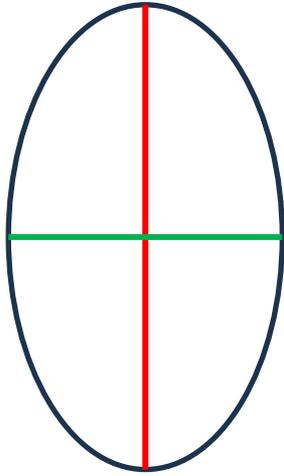
La figura illustra che in funzione del ritardo delle onde che interferiscono nell'attraversare l'analizzatore, i colori componenti della luce bianca vengono intensificati o attenuati o cancellati

$$\text{RITARDO} = d \cdot (n_\gamma - n_\alpha)$$

$$(n_\gamma - n_\alpha) = \text{birifrangenza (linee)}$$



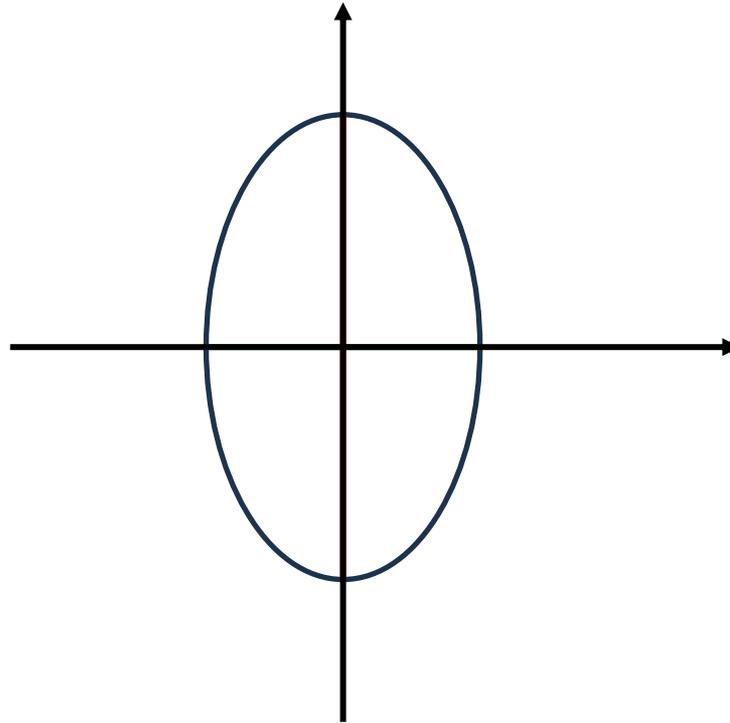
RITARDO distinto in vari ordini di colori (in nm dove $1\text{nm} = 10^{-3}\mu = 10\text{\AA} = 10^{-7}\text{cm}$)



Indicatrice Uniassica +

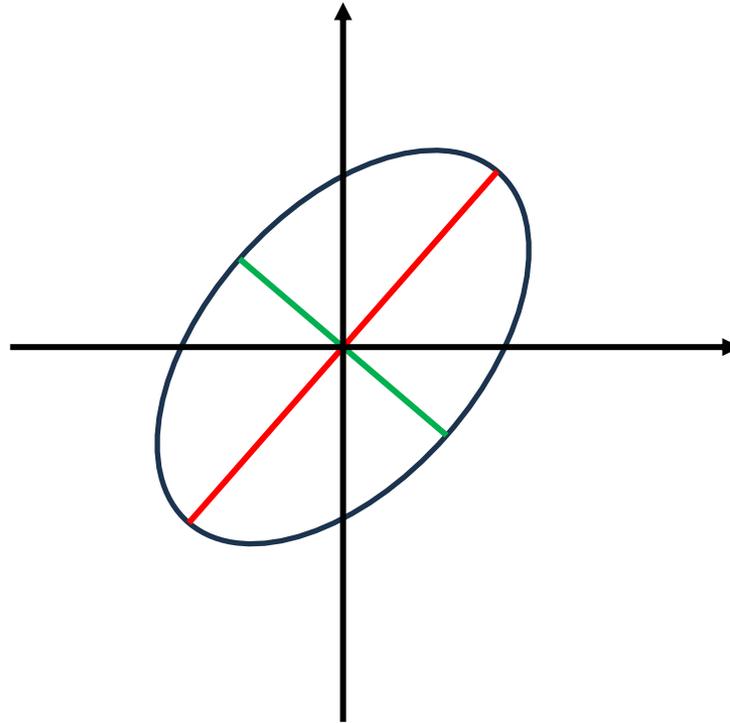
Rosso = ϵ

Verde = ω



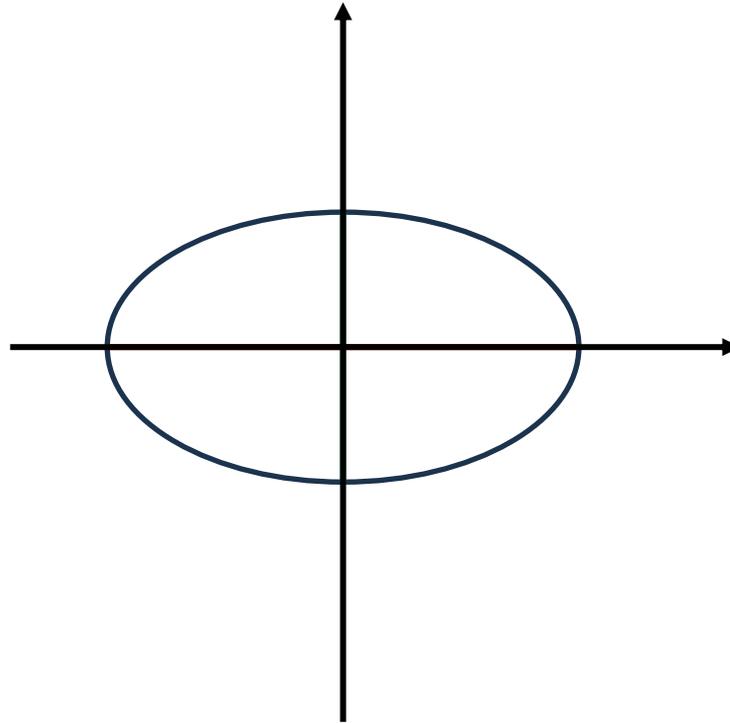
1

ESTINZIONE

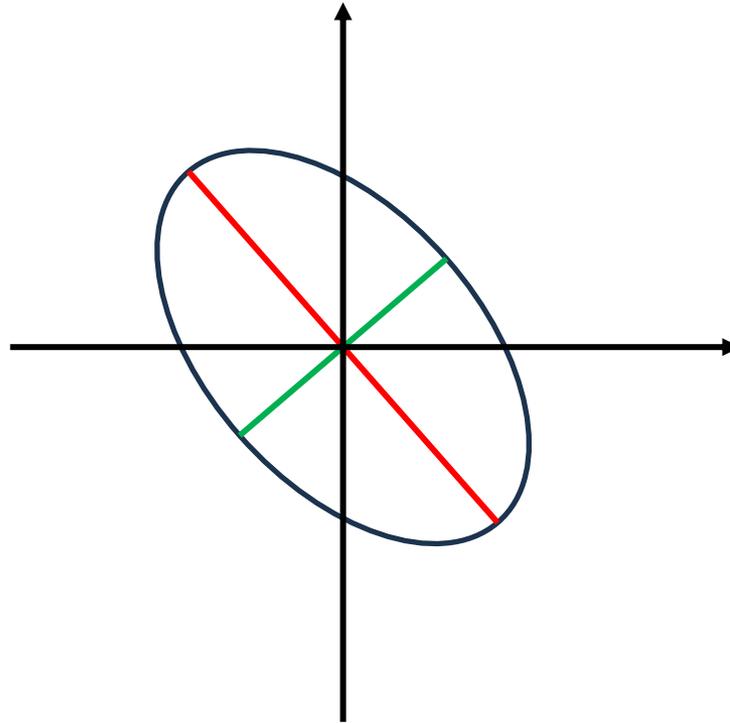


MASSIMA ILLUMINAZIONE

2

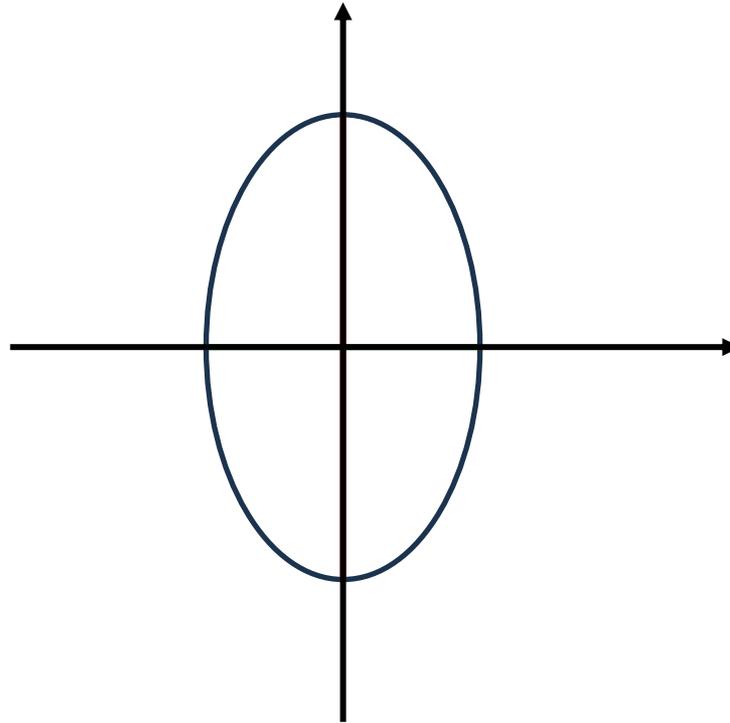


ESTINZIONE

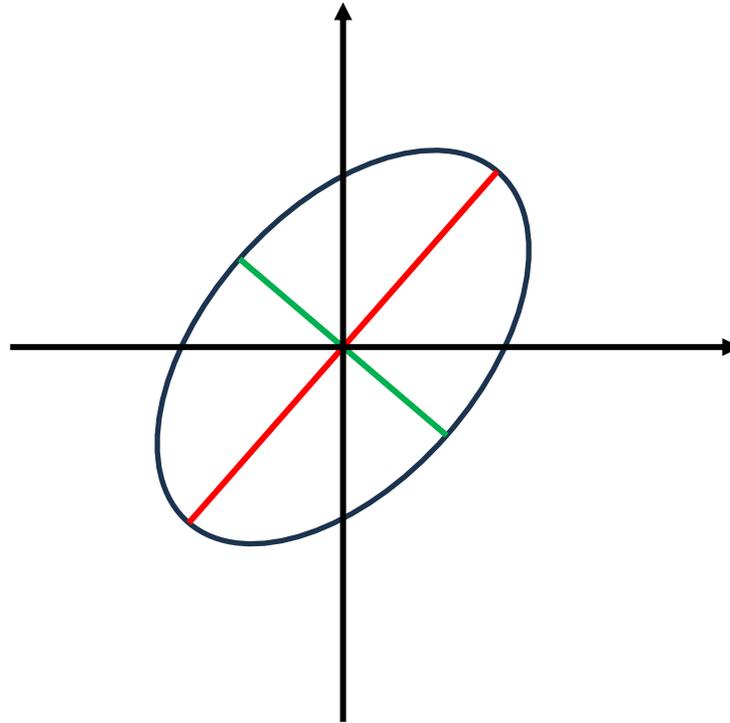


MASSIMA ILLUMINAZIONE

3

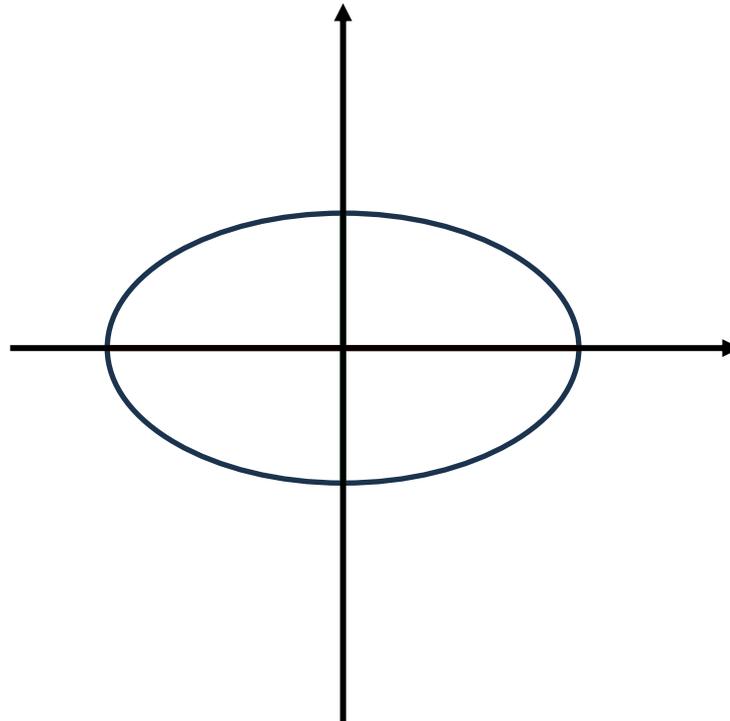


ESTINZIONE

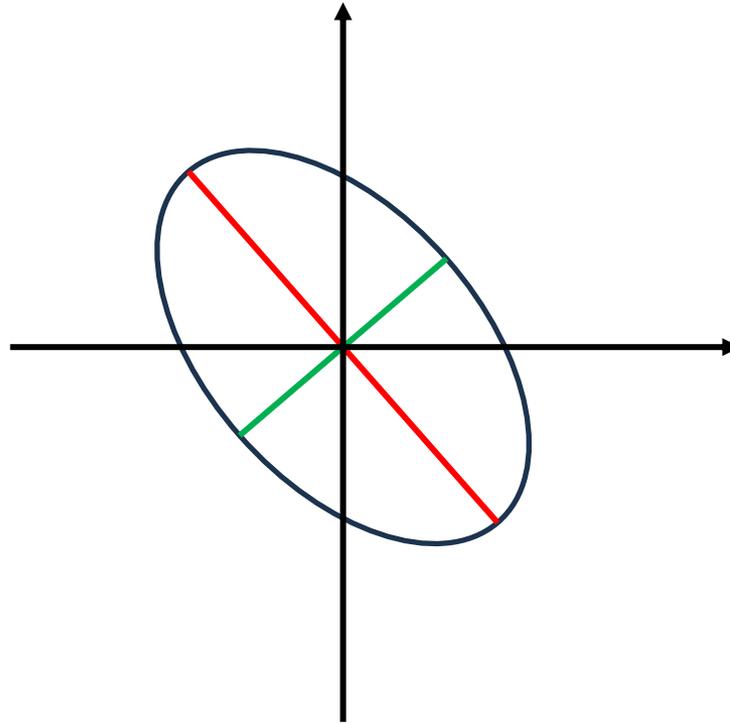


MASSIMA ILLUMINAZIONE

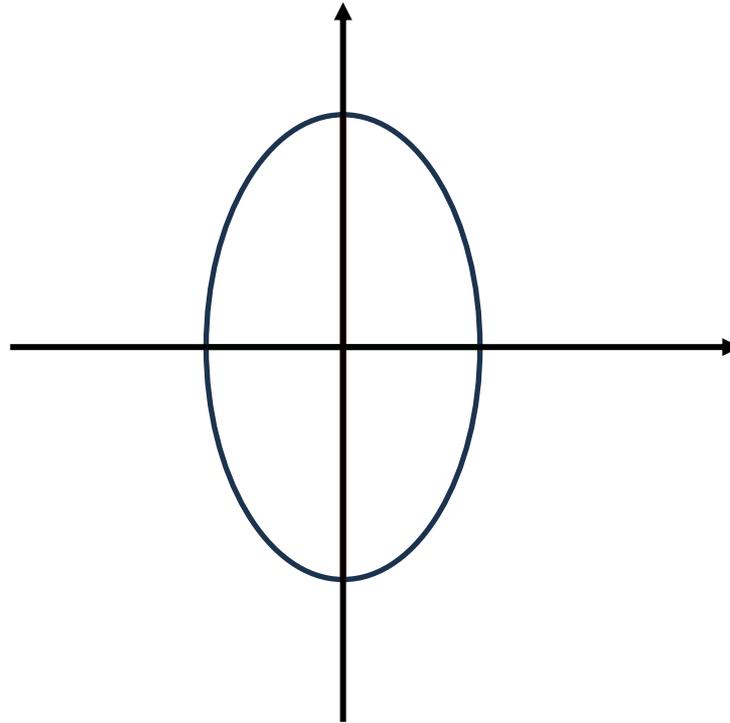
4



ESTINZIONE



MASSIMA ILLUMINAZIONE

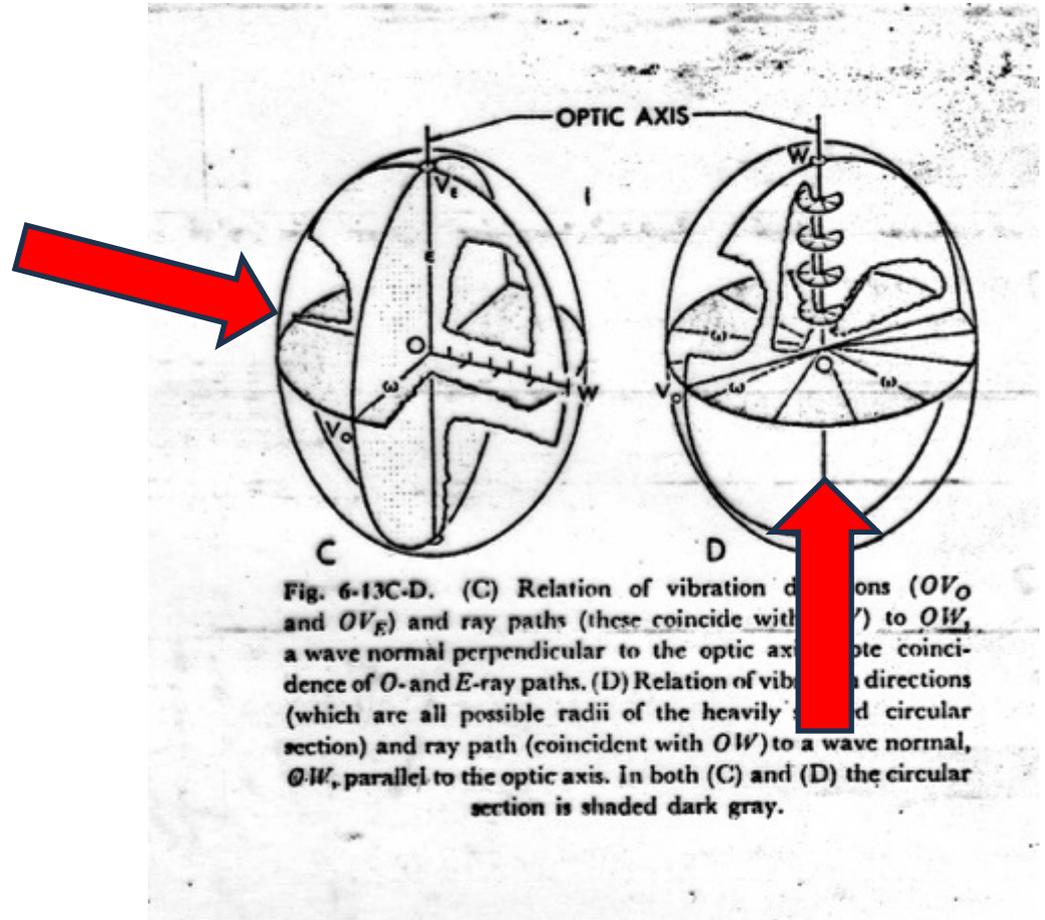


1

ESTINZIONE



Raggio luminoso



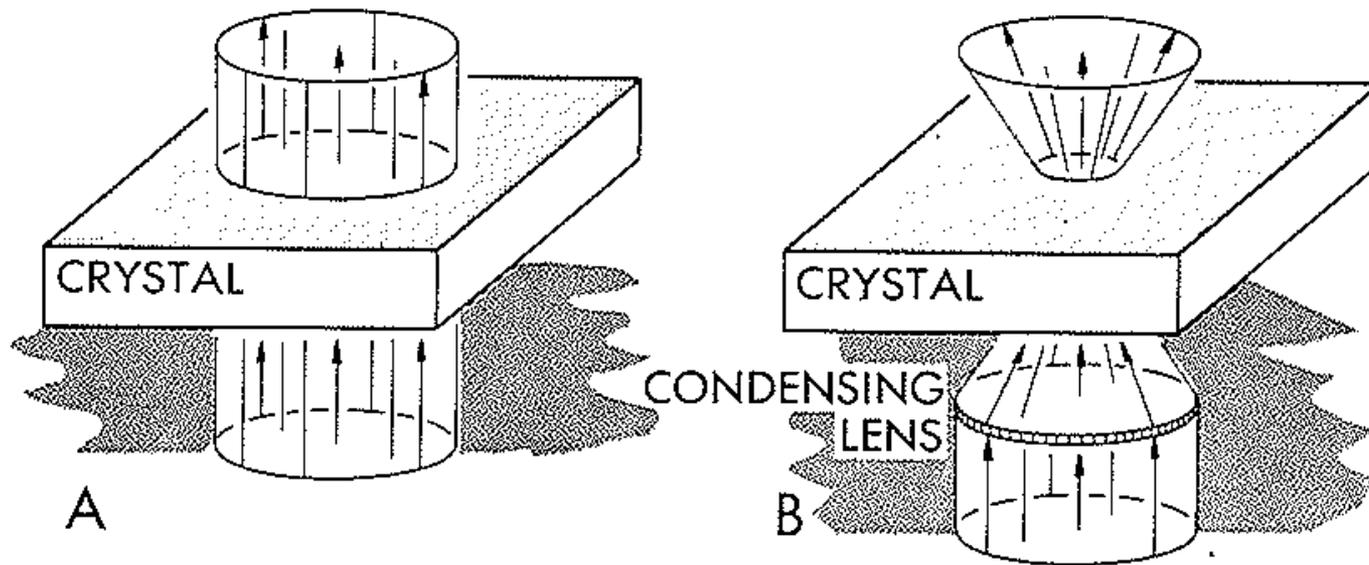


Fig. 7-10. Comparison of the ray paths for orthoscopic illumination (A) and conosopic illumination (B). For the actual situation the rays shown in (A) would be slightly convergent. They become increasingly parallel, however, as the apertures are decreased (for example, by closing down the iris diaphragm or inserting a lower power lens).

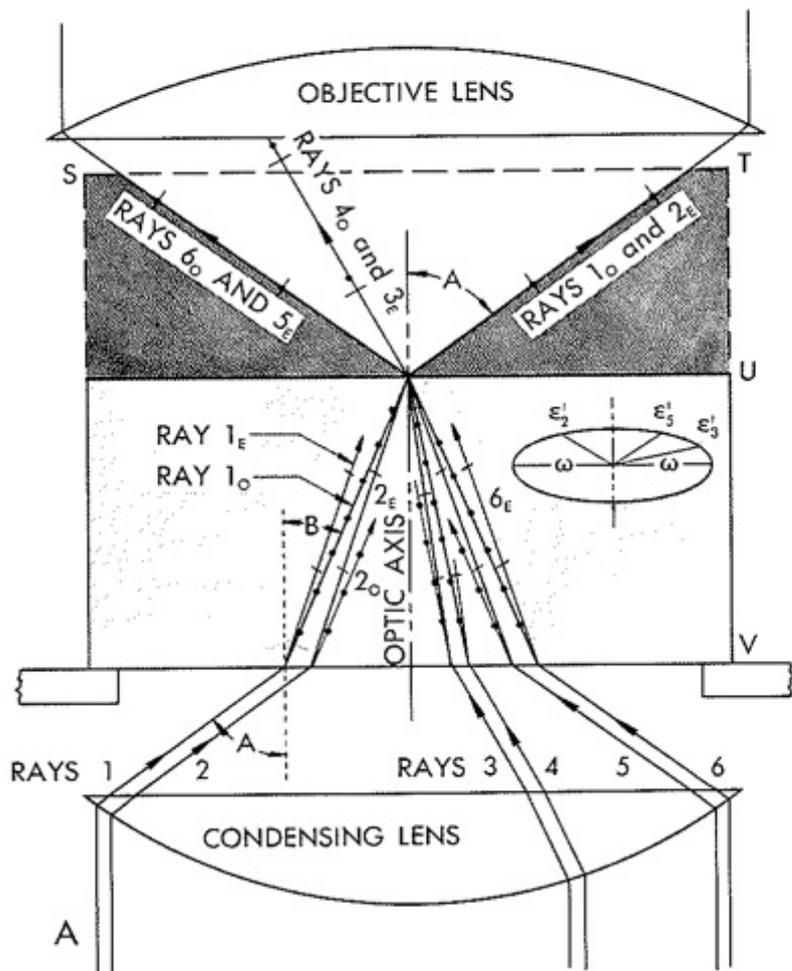
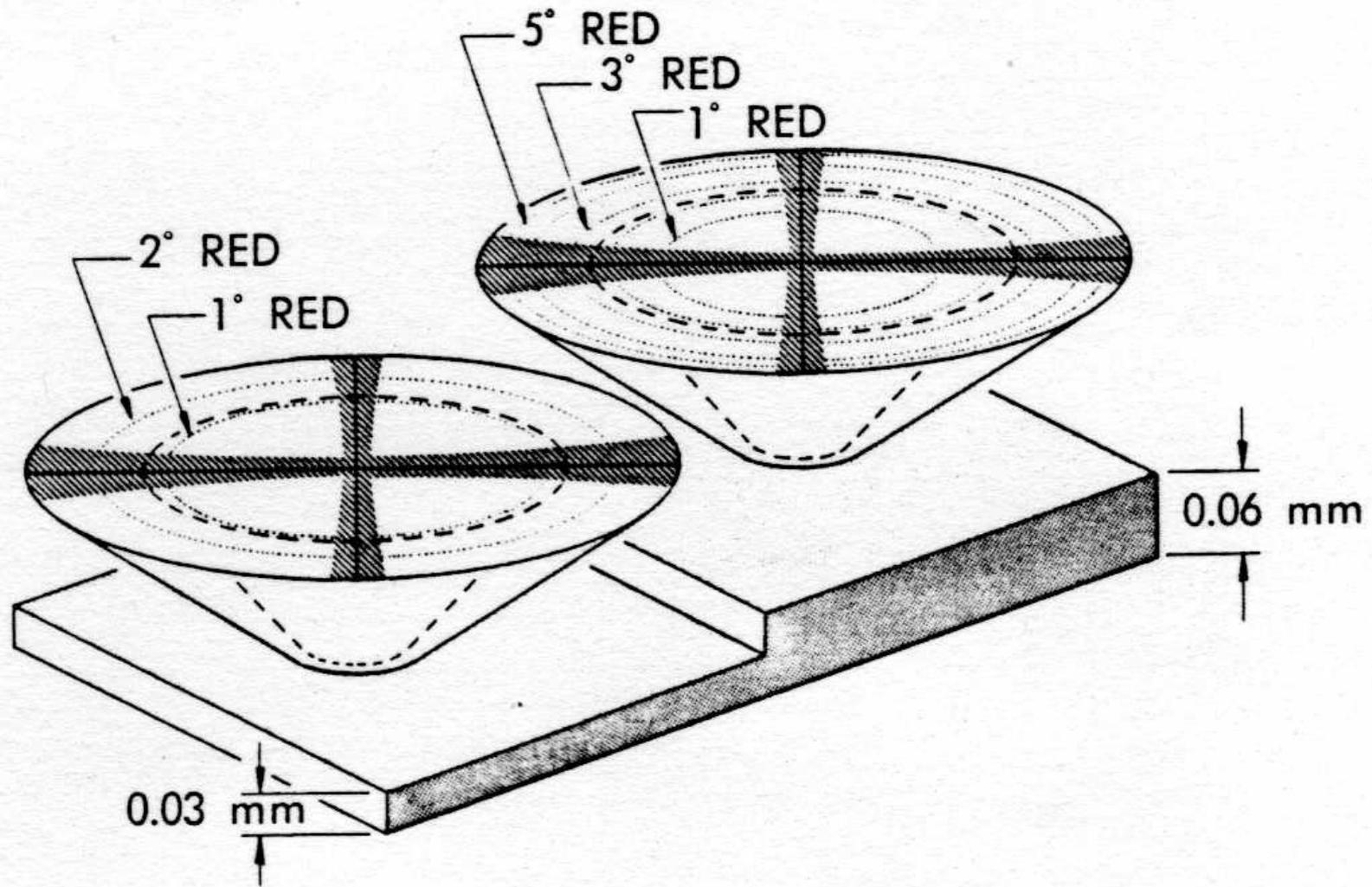
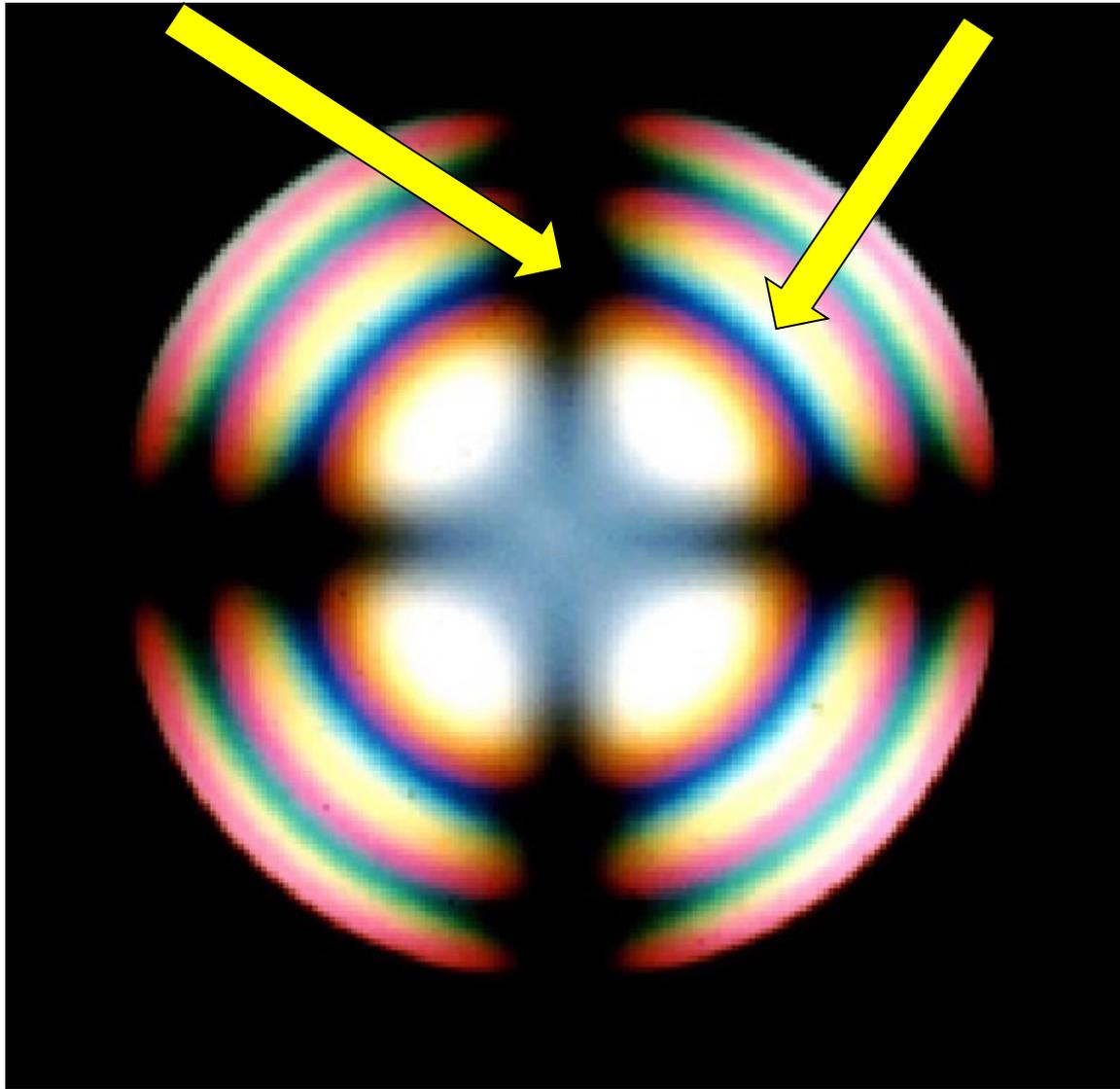


Fig. 7-13. (A) Cross-sectional view of a conoscopically illuminated uniaxial crystal whose optic axis is perpendicular to stage. (B) Cones of equal retardation for same in perspective view. *STUV* is the cross-sectional plane drawn in (A). Crystal thickness is highly exaggerated.

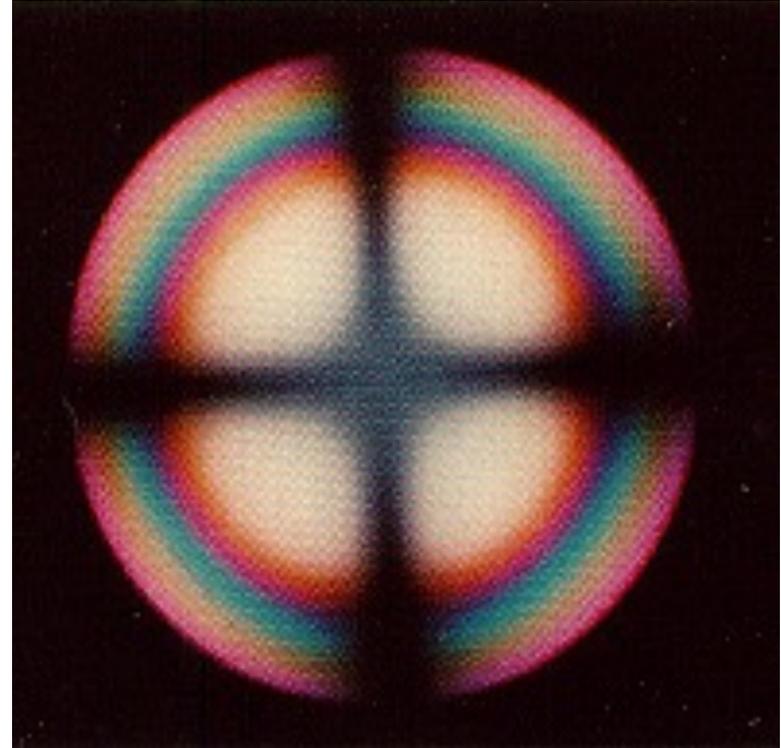
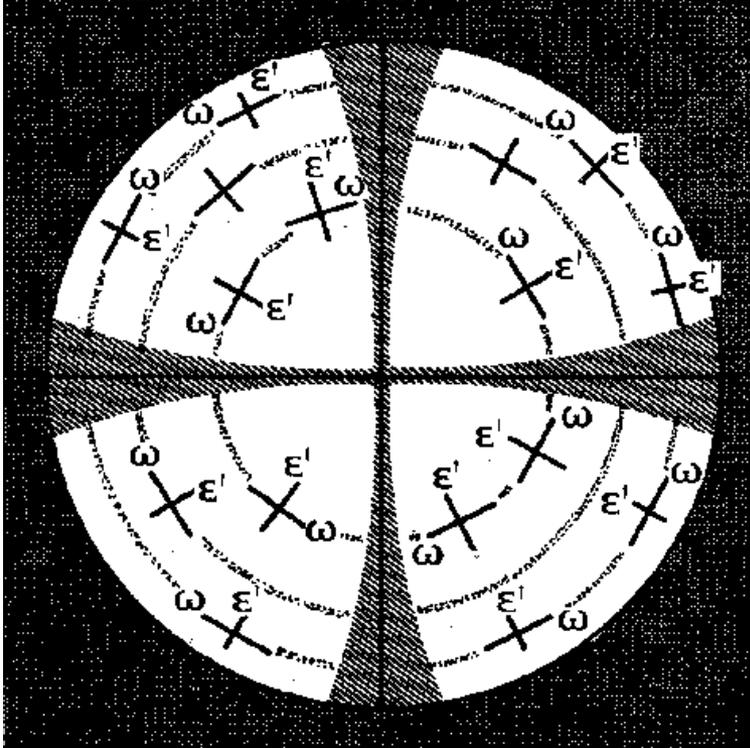


ISOGIRE

ISOCROMATICHE

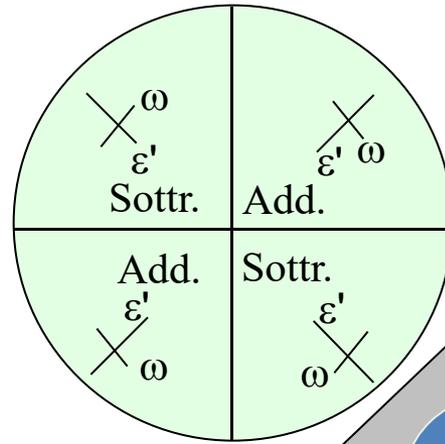
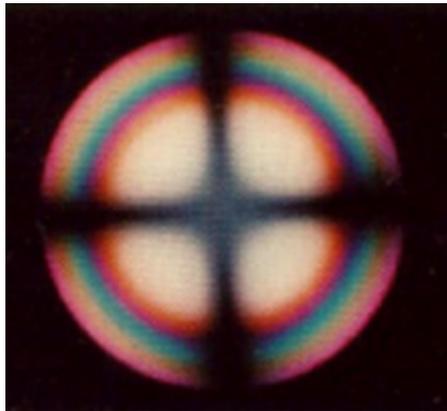
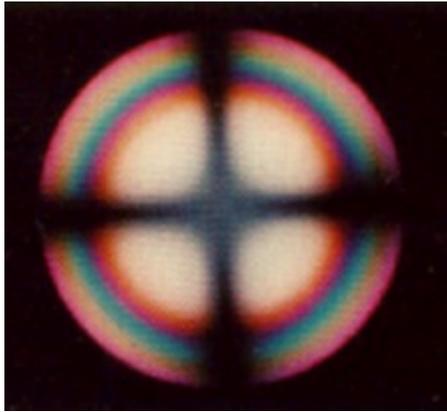


Rispetto alle isocromatiche ε è sempre radiale e ω è sempre tangenziale

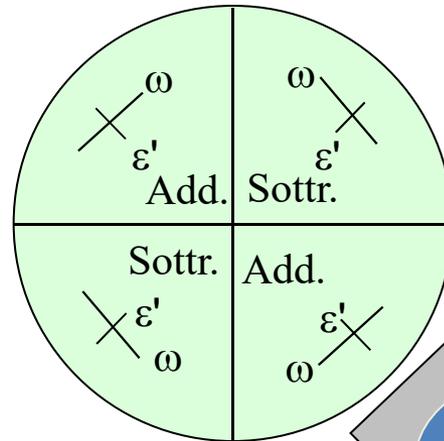
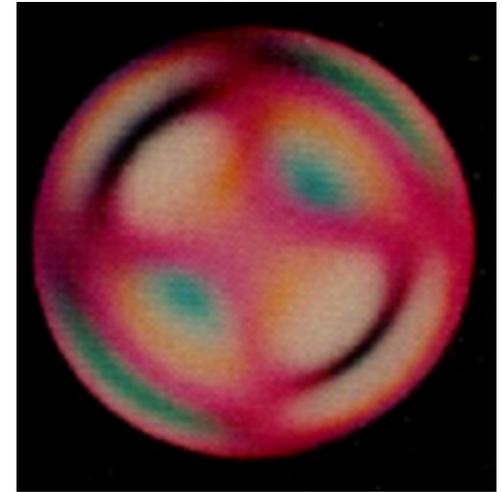


per $\varepsilon > \omega$ il cristallo è positivo (+)
per $\varepsilon < \omega$ il cristallo è negativo (-)

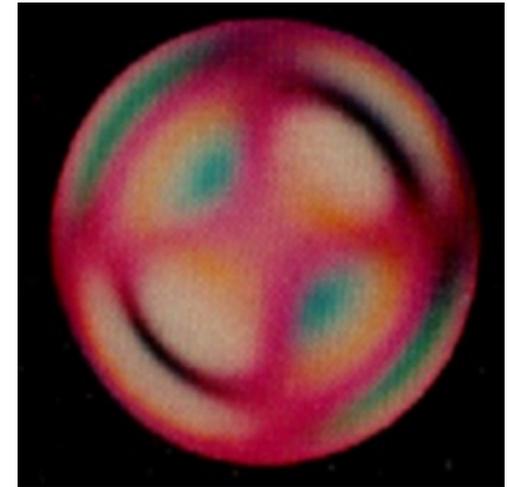
CRISTALLO UNIASSICO : SEGNO OTTICO



+

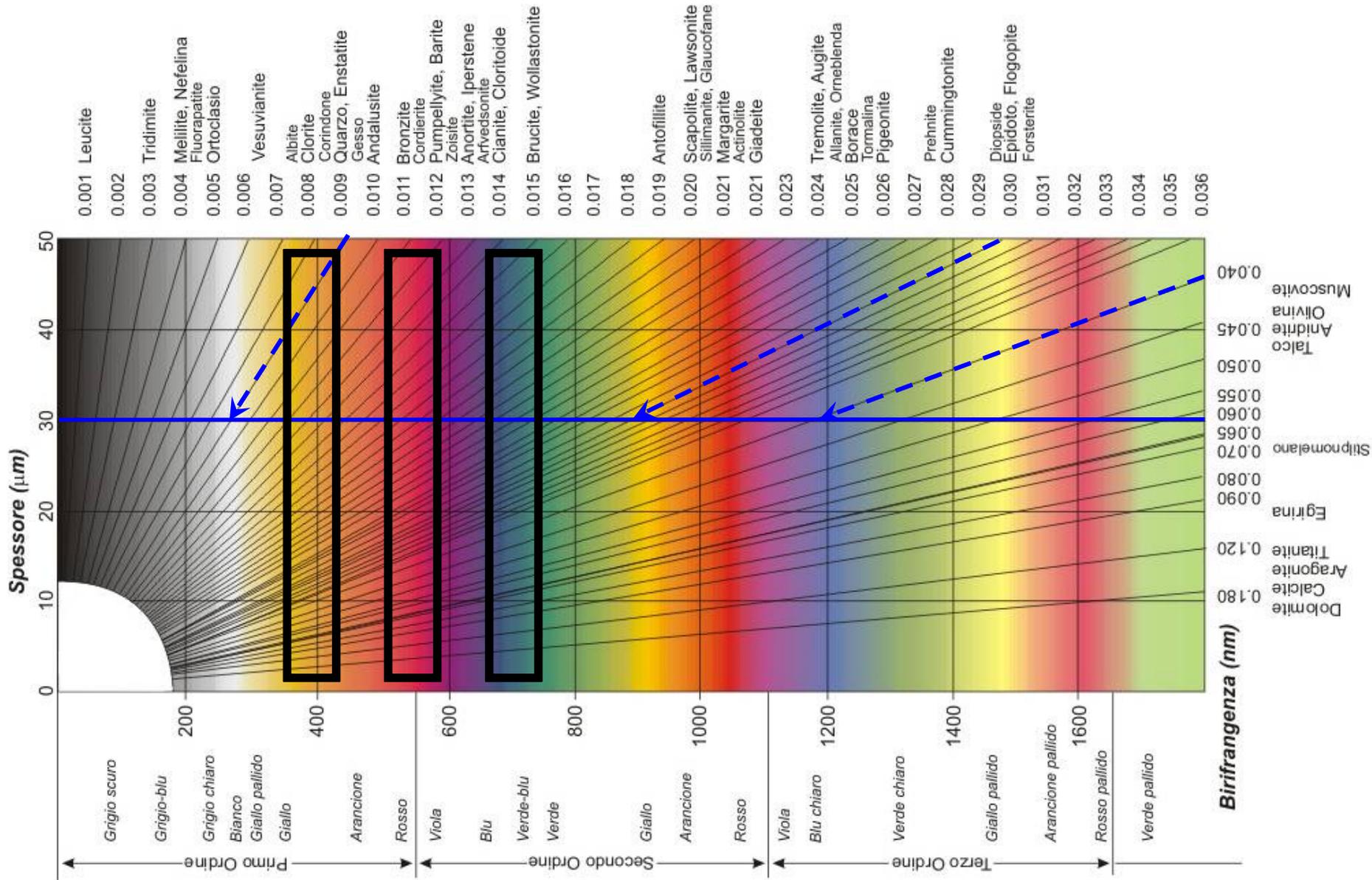


-



$$\text{RITARDO} = s(n_\gamma - n_\alpha)$$

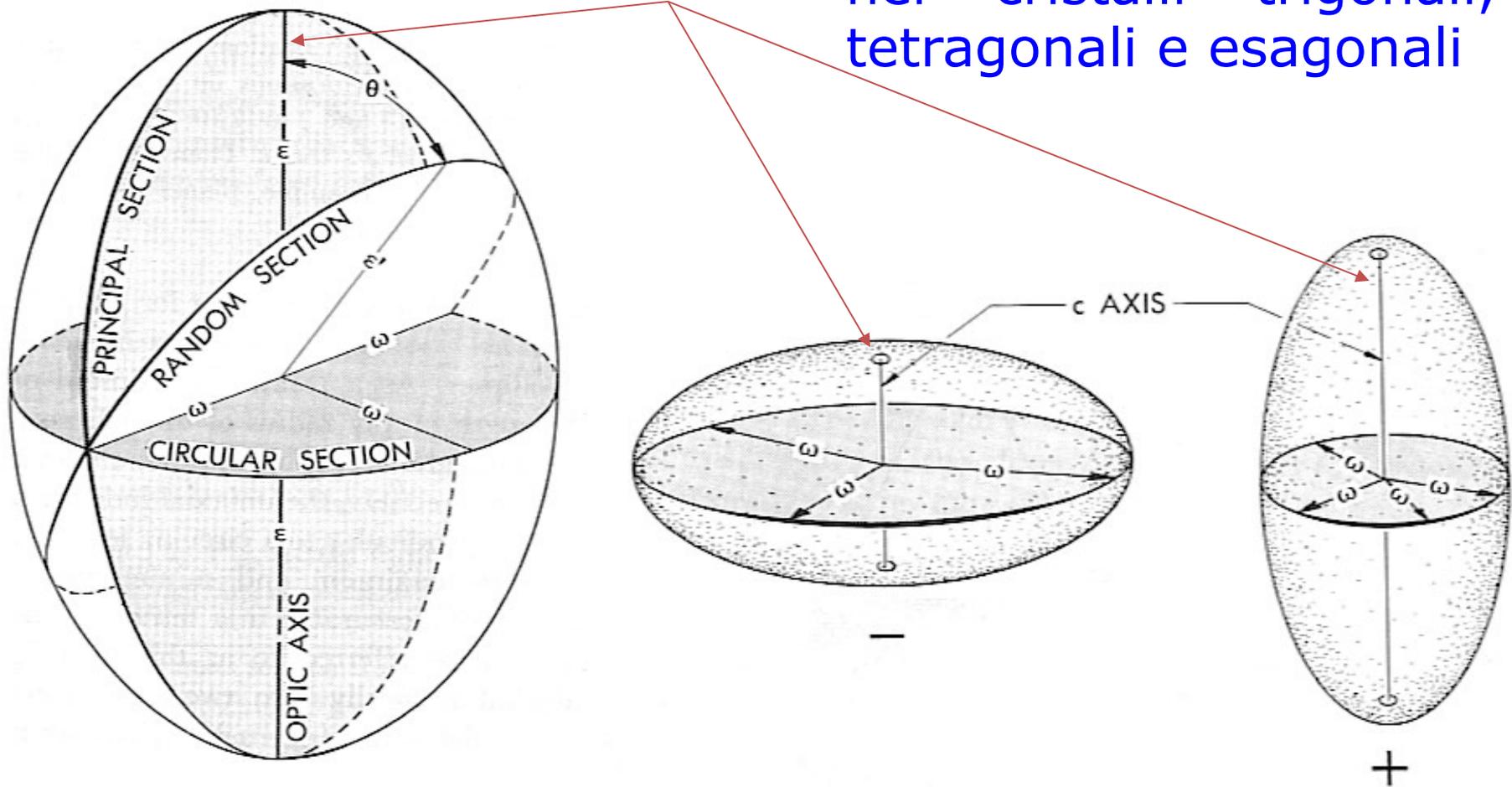
$$(n_\gamma - n_\alpha) = \text{birifrangenza (linee)}$$

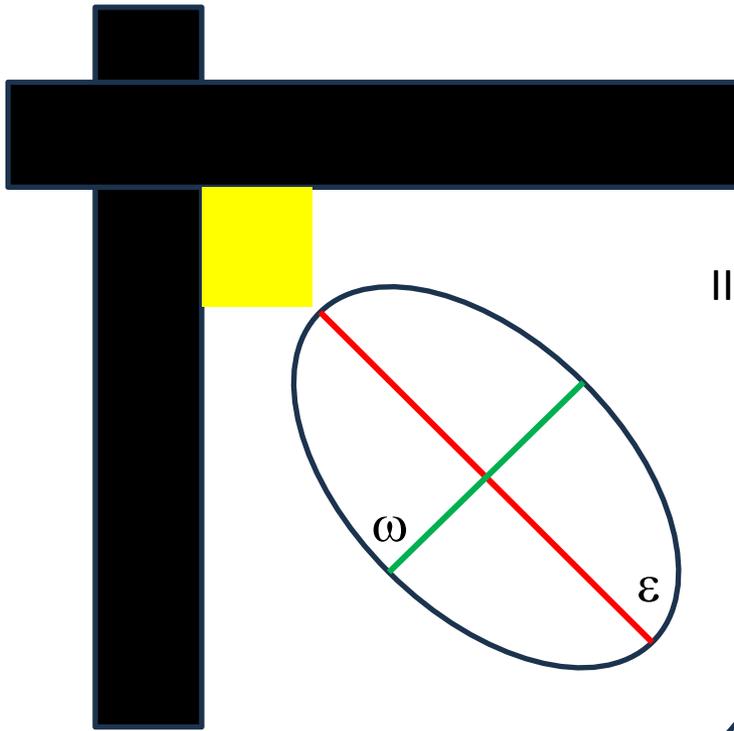


RITARDO distinto in vari ordini di colori (in nm dove $1\text{nm} = 10^{-3}\mu = 10\text{\AA} = 10^{-7}\text{cm}$)

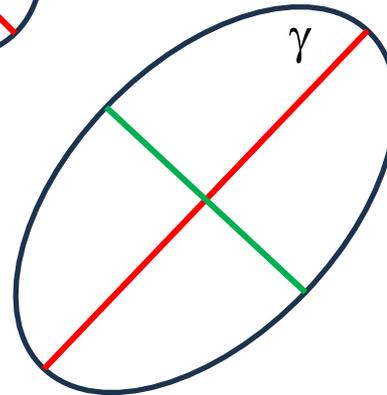
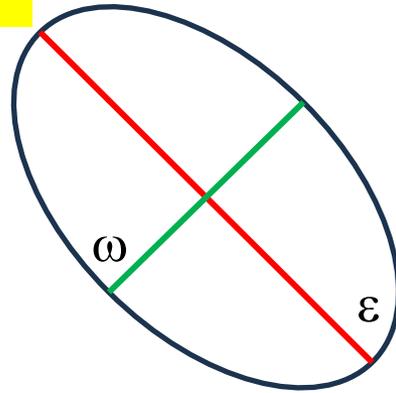
Uniaxial Indicatrix

Asse Ottico = l'asse C
nei cristalli trigonali,
tetragonali e esagonali



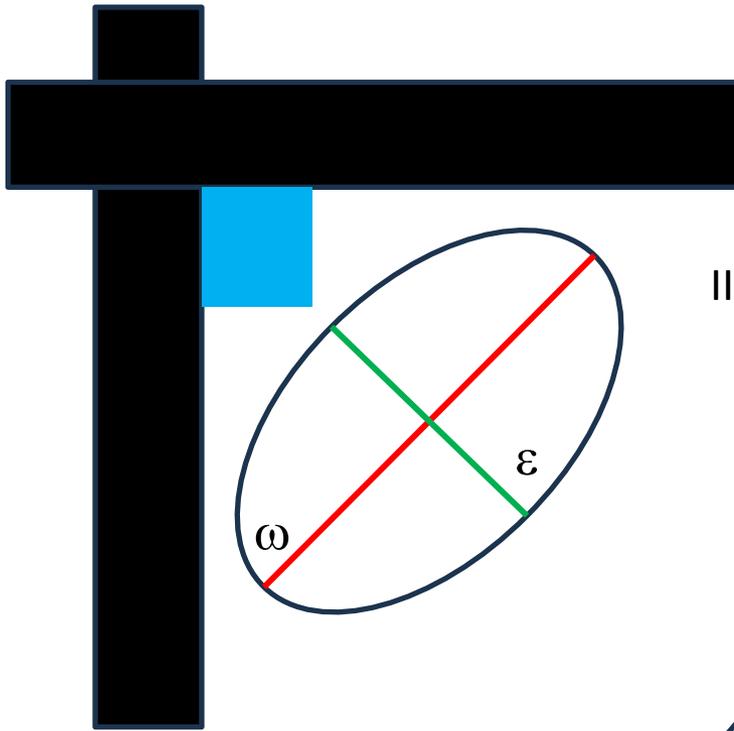


II° quadrante Figura Interferenza

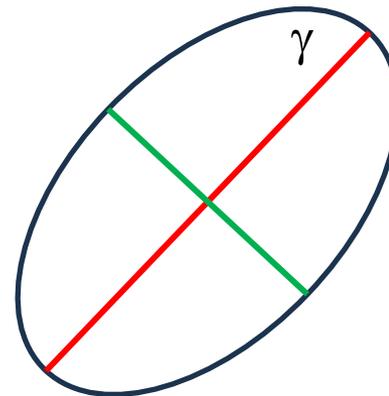
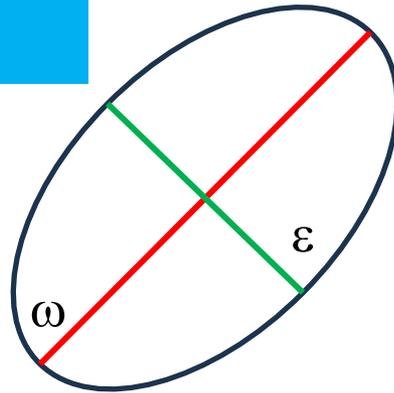


Lamina di Gesso

Sottrazione di RITARDI $\varepsilon > \omega$ cristallo uniassico
POSITIVO

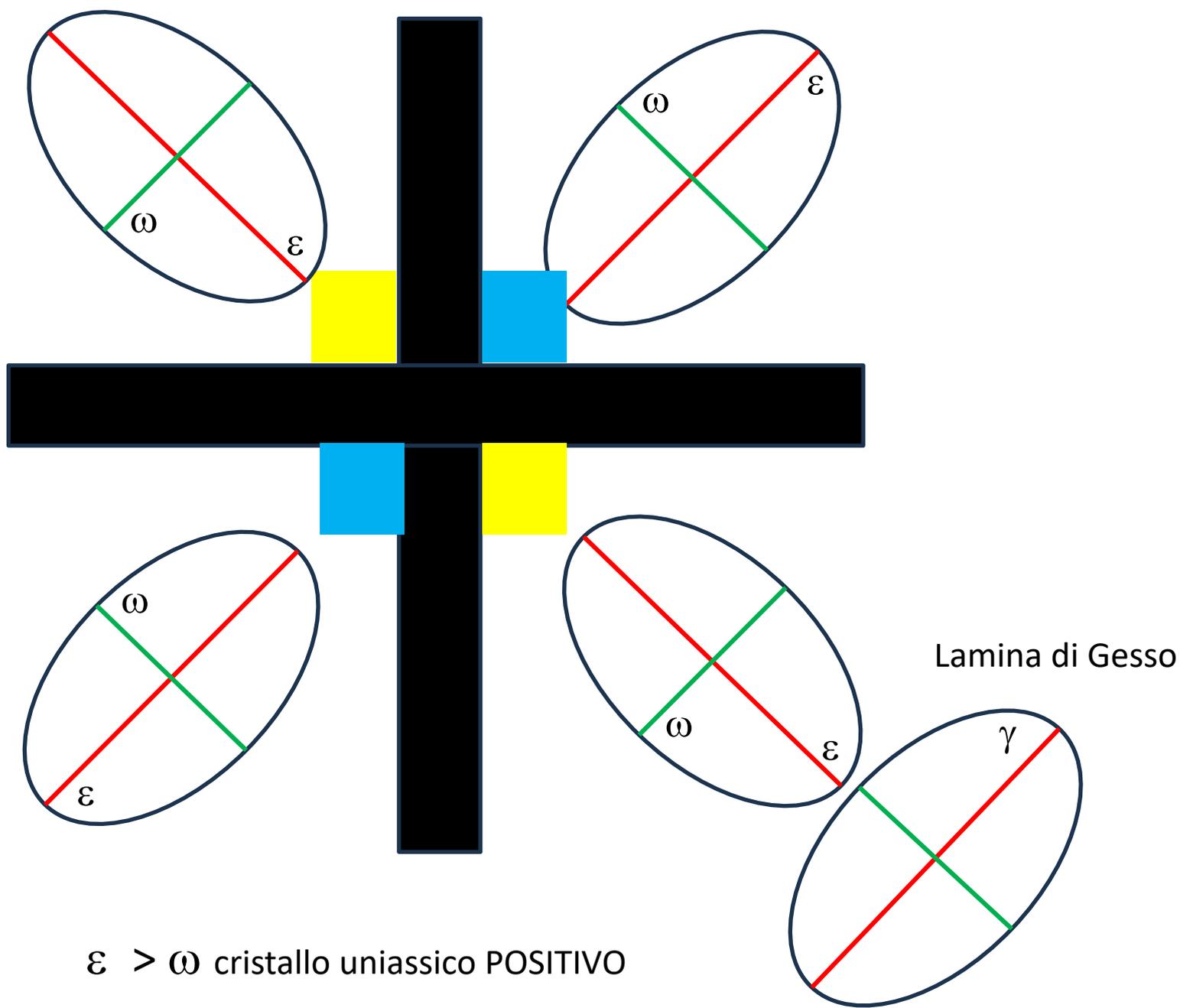


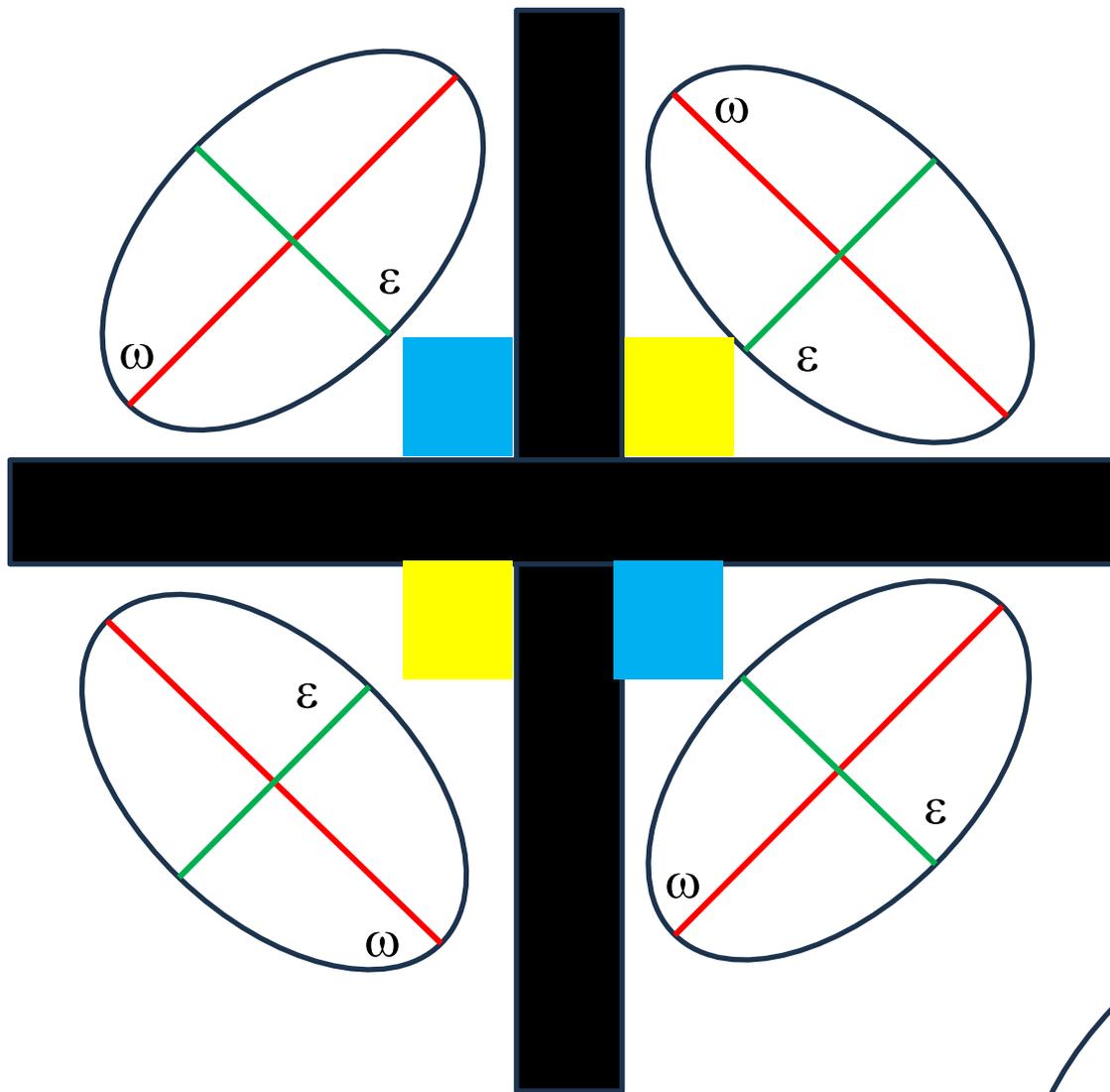
II° quadrante Figura Interferenza



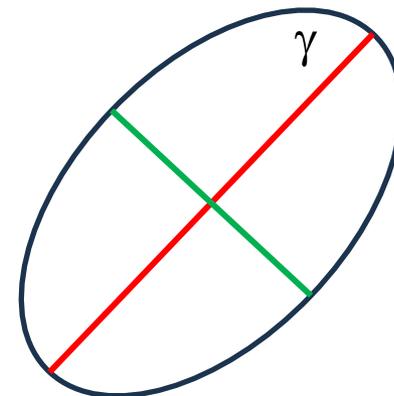
Lamina di Gesso

Somma di RITARDI $\omega > \epsilon$ cristallo uniassico
NEGATIVO





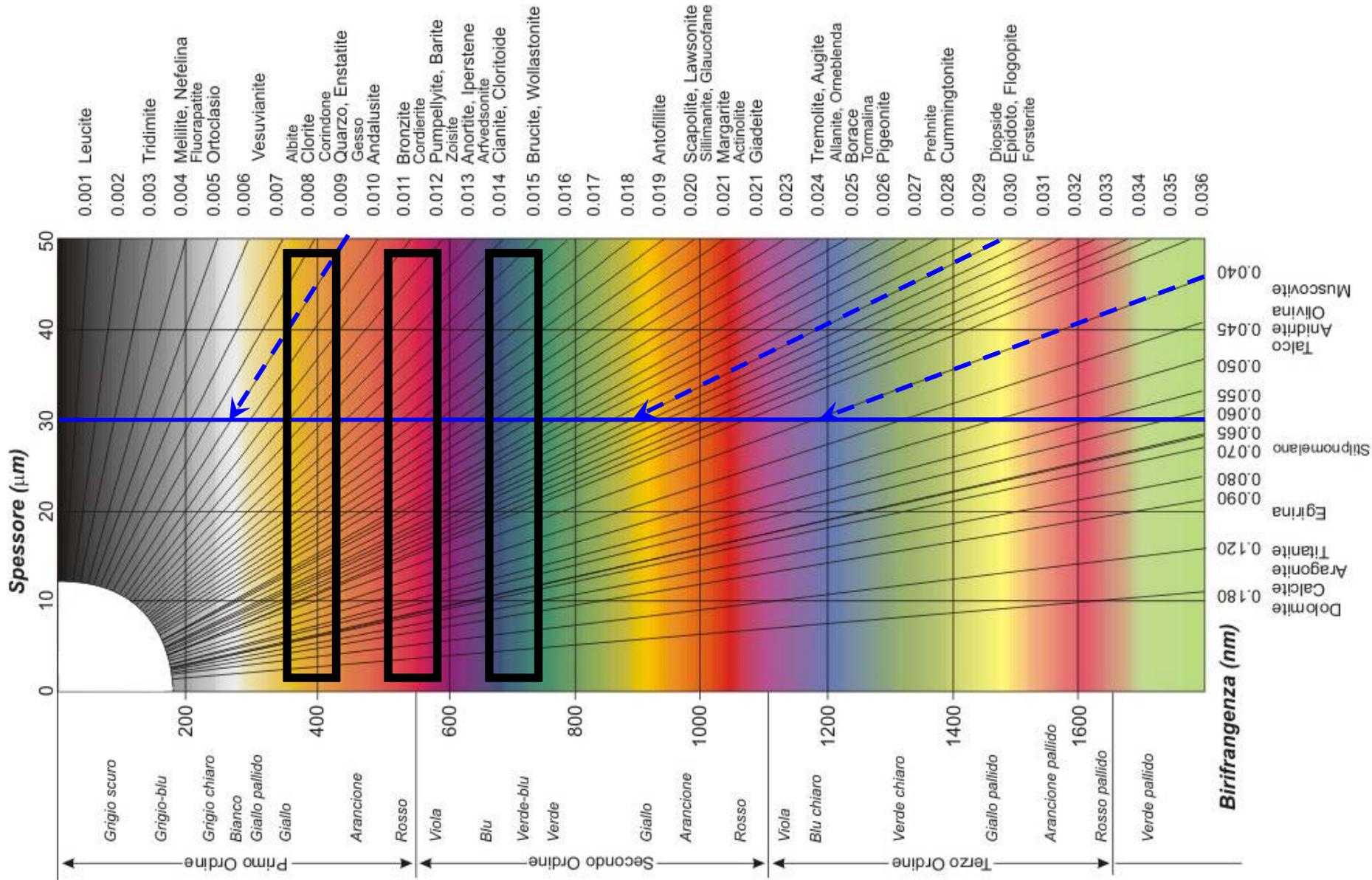
Lamina di Gesso



$\omega > \varepsilon$ cristallo uniassico NEGATIVO

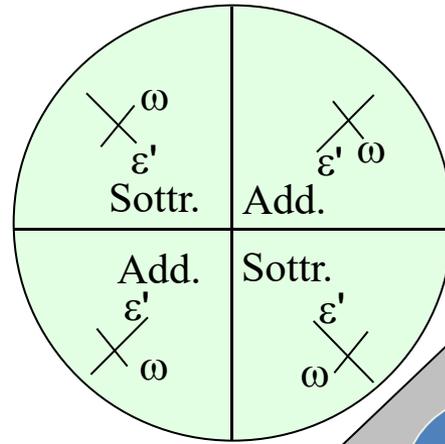
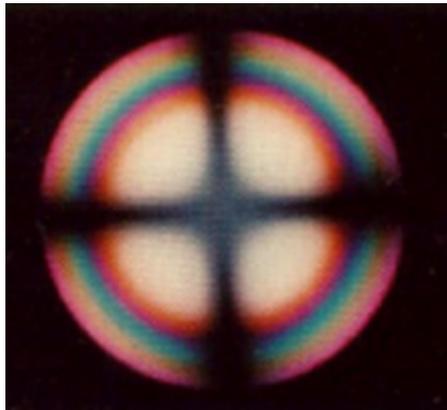
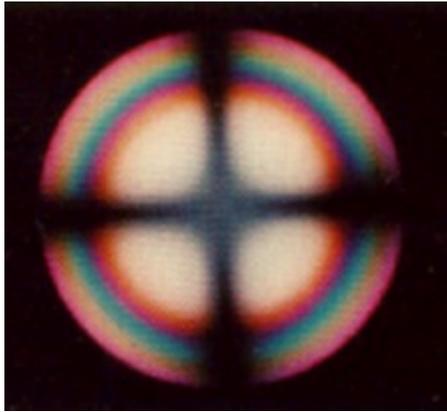
$$\text{RITARDO} = s(n_\gamma - n_\alpha)$$

$$(n_\gamma - n_\alpha) = \text{birifrangenza (linee)}$$

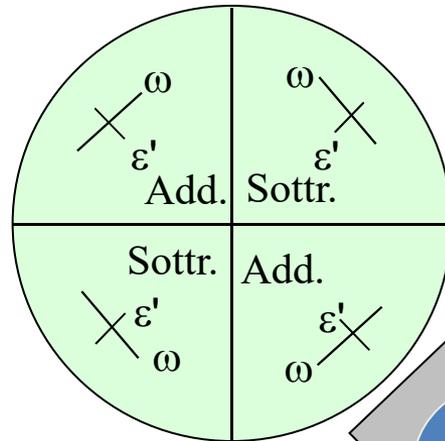
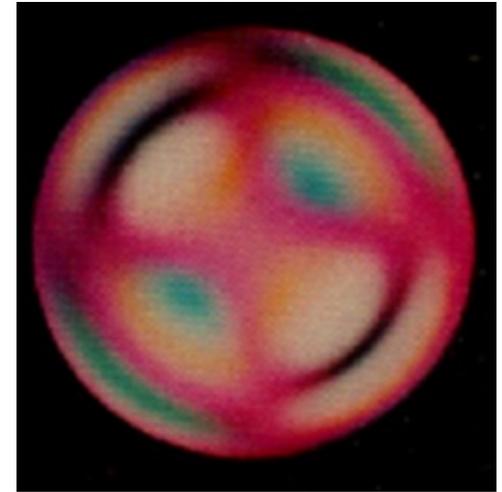


RITARDO distinto in vari ordini di colori (in nm dove $1\text{nm} = 10^{-3}\mu = 10\text{\AA} = 10^{-7}\text{cm}$)

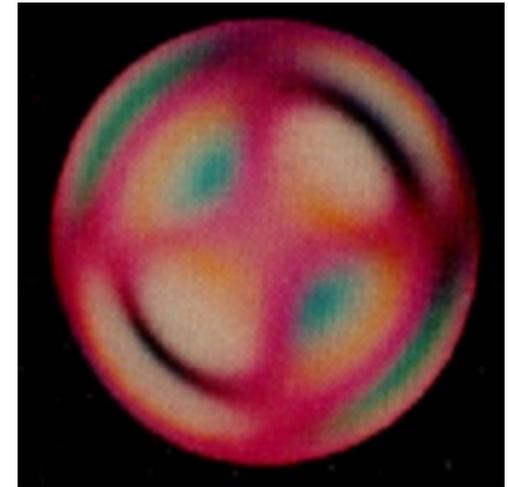
CRISTALLO UNIASSICO : SEGNO OTTICO

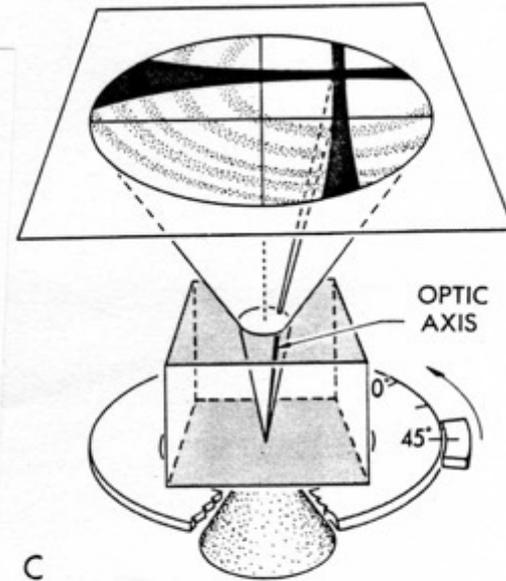
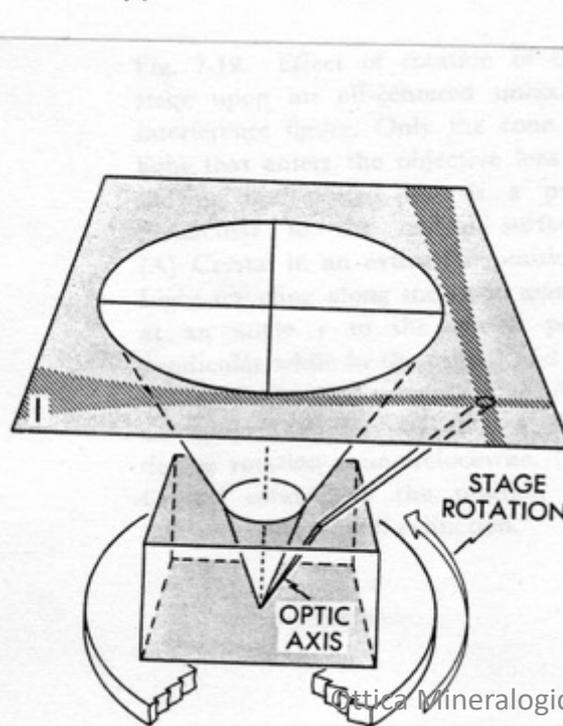
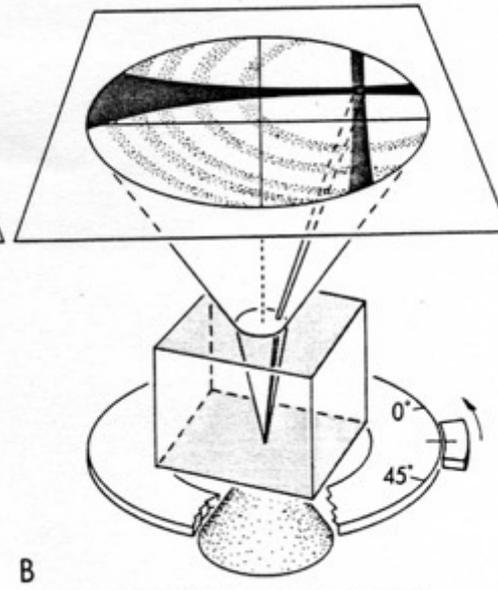
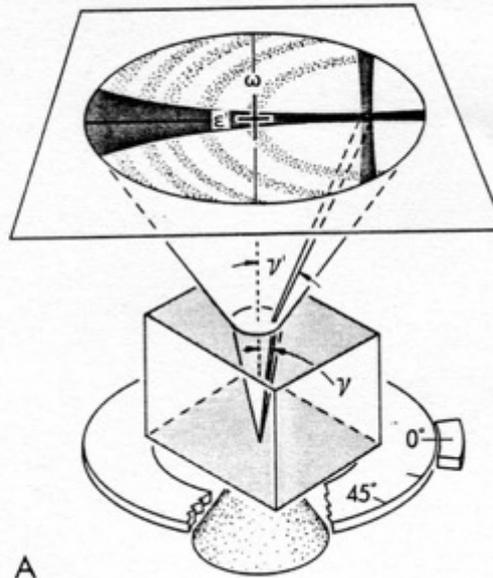


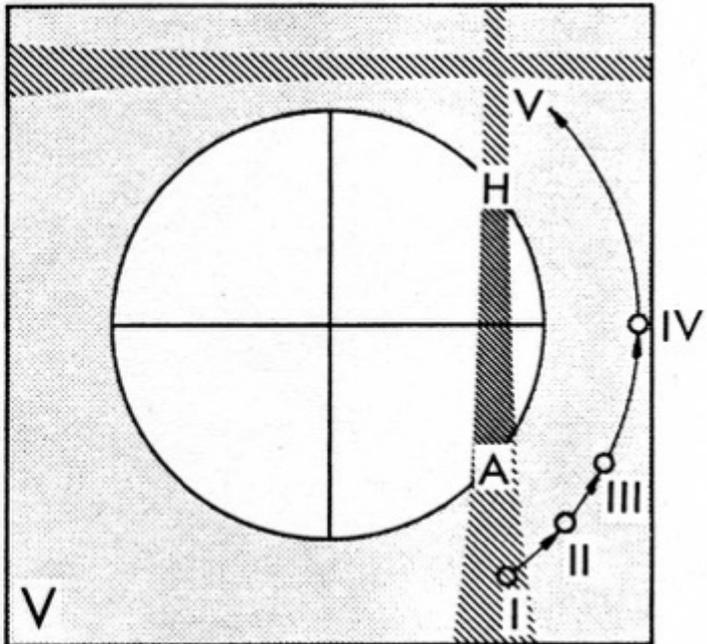
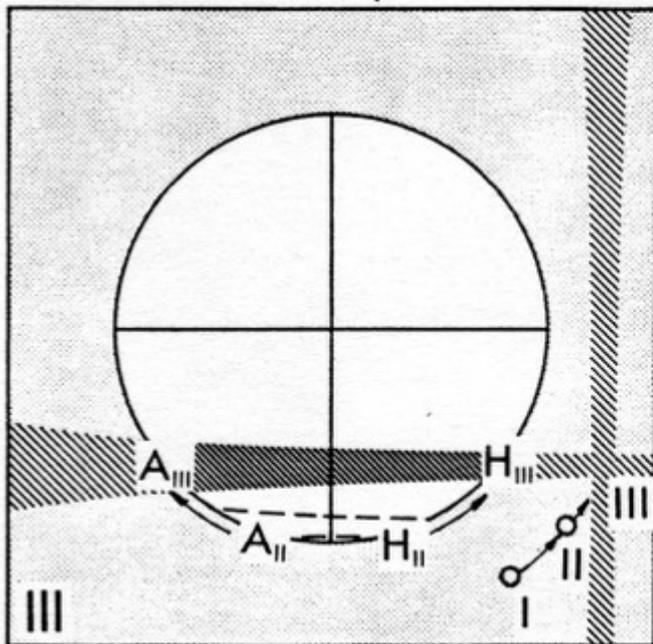
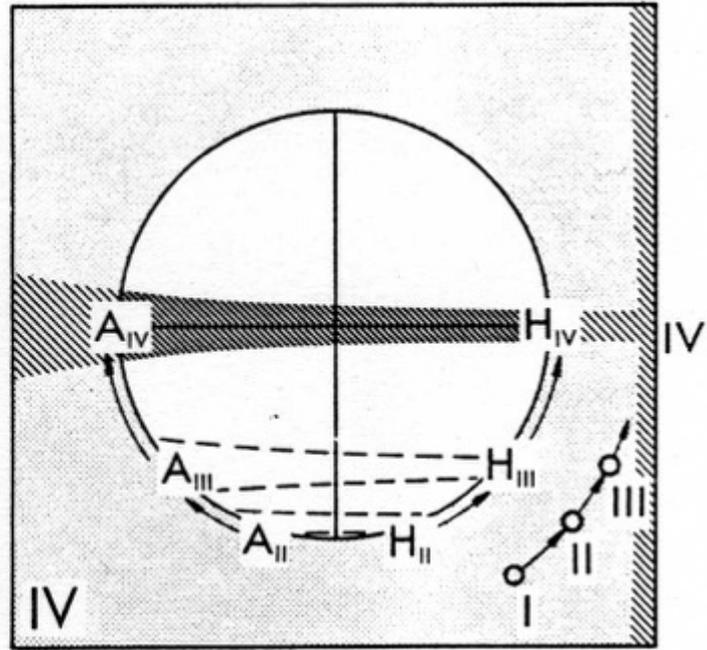
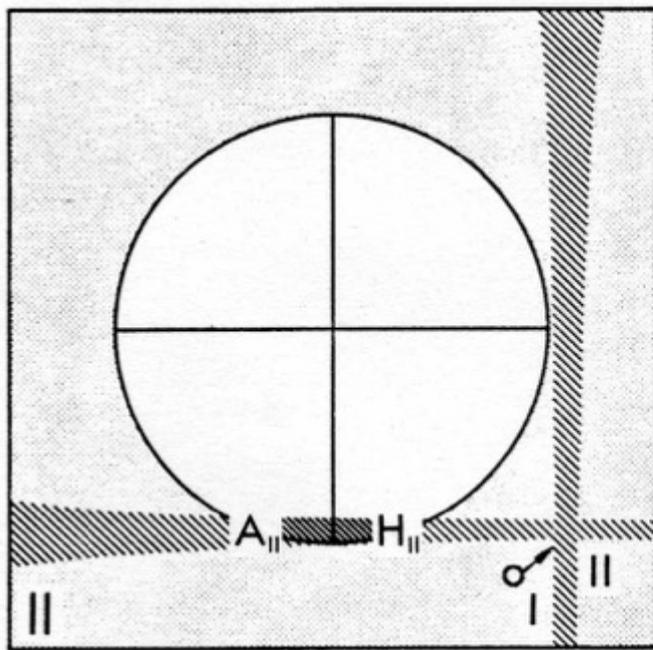
+



-

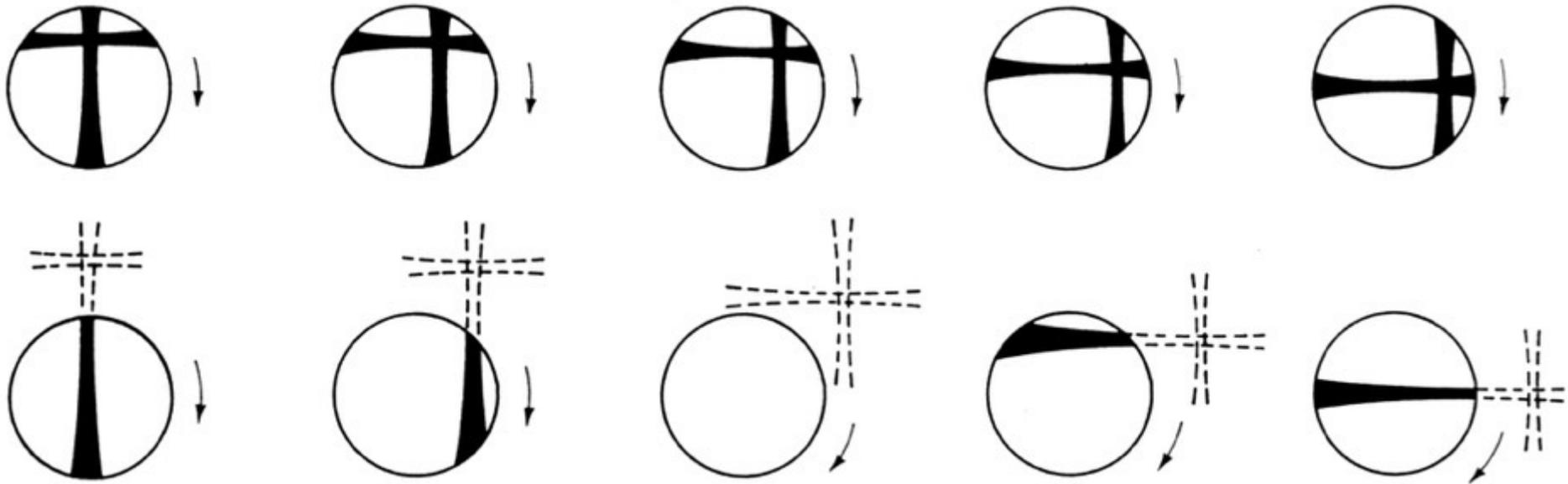




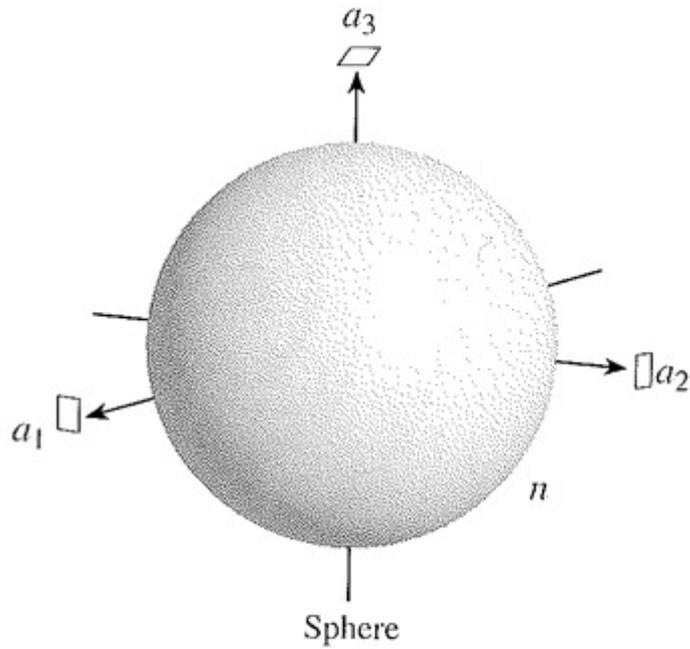


CRISTALLO UNIASSICO

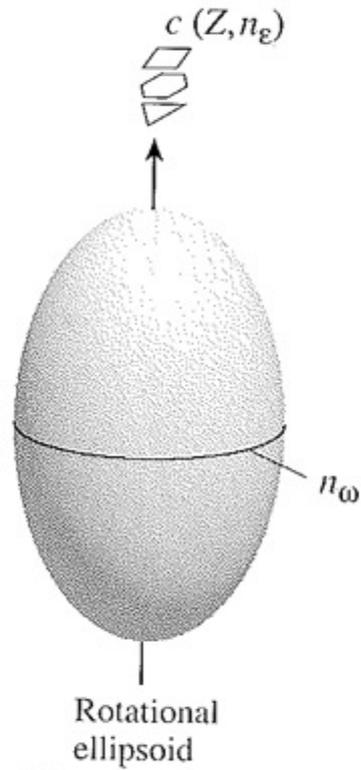
sezioni diversamente inclinate rispetto all' AO e per diverse rotazioni del piatto



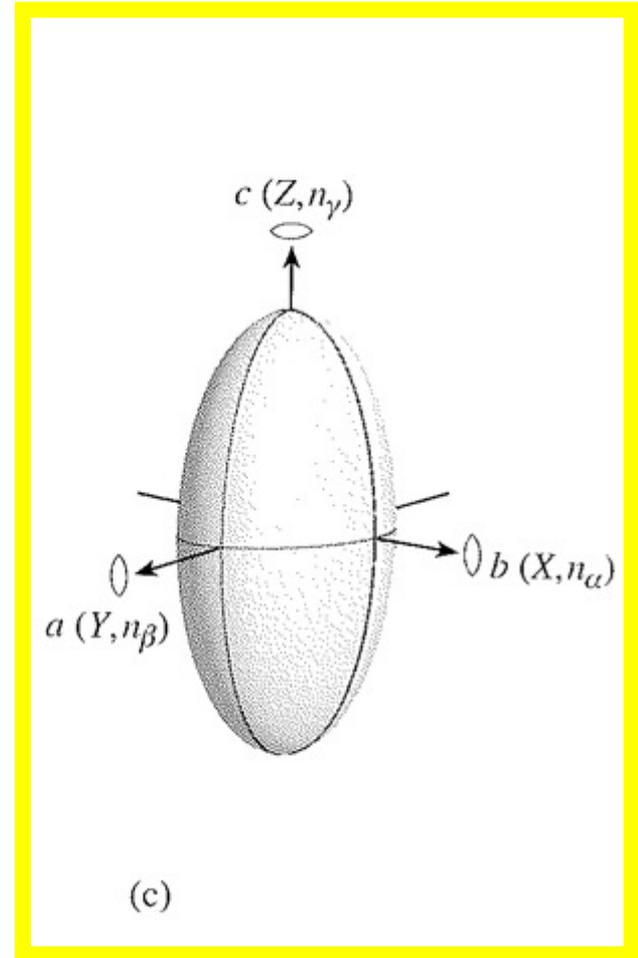
Indicatrici Ottiche



(a)



(b)



(c)

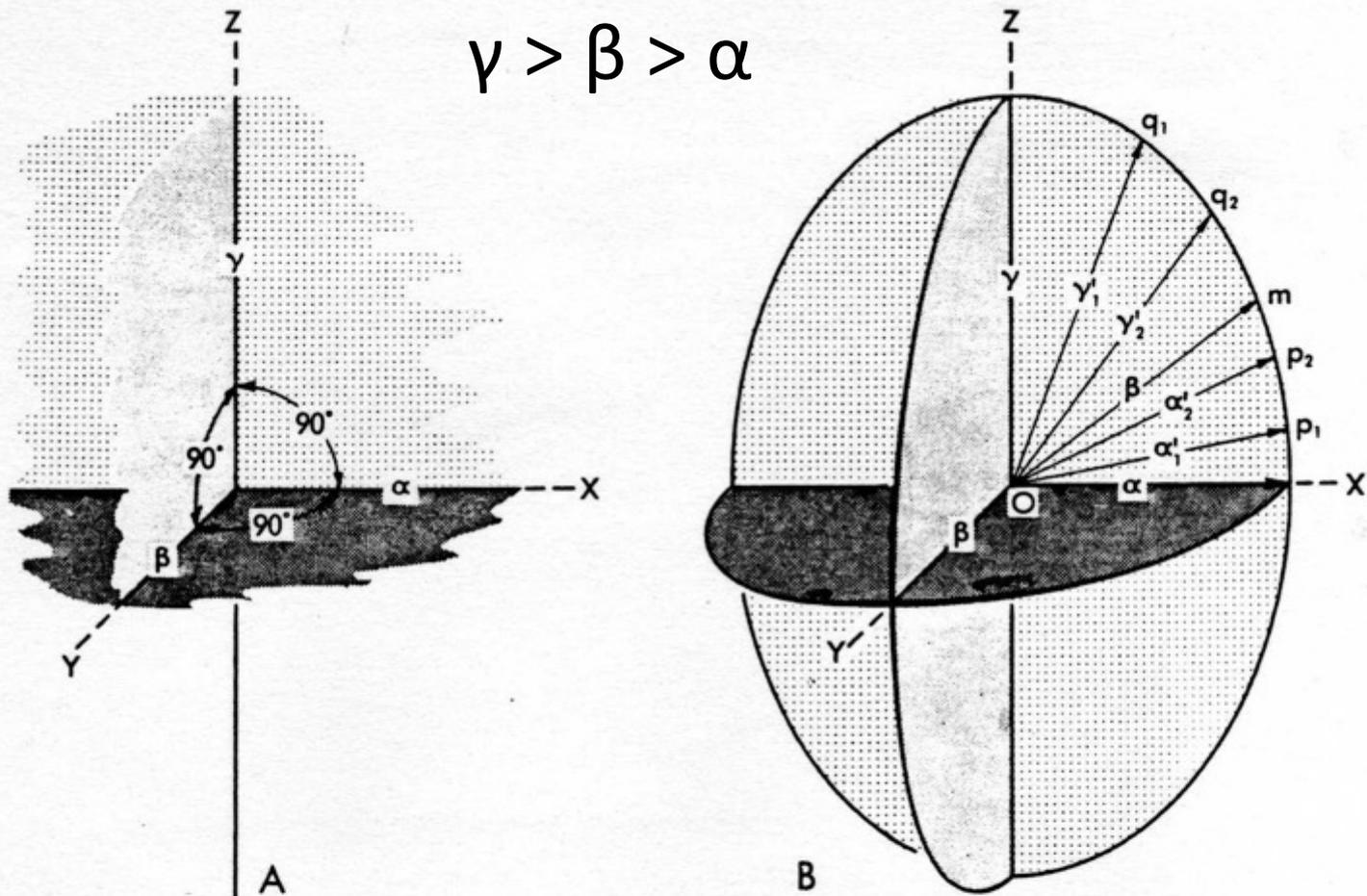


Fig. 9-1. (A) The three, mutually perpendicular, principal vibration axes, X , Y , and Z , and the common symbols for the indices of refraction of a biaxial mineral for light vibrating parallel to them. (B) Elliptical distribution of the index of refraction (as shown by the vector lengths) for light vibrating parallel to op_1 , op_2 , om , oq_2 , oq_1 within the ZX plane.

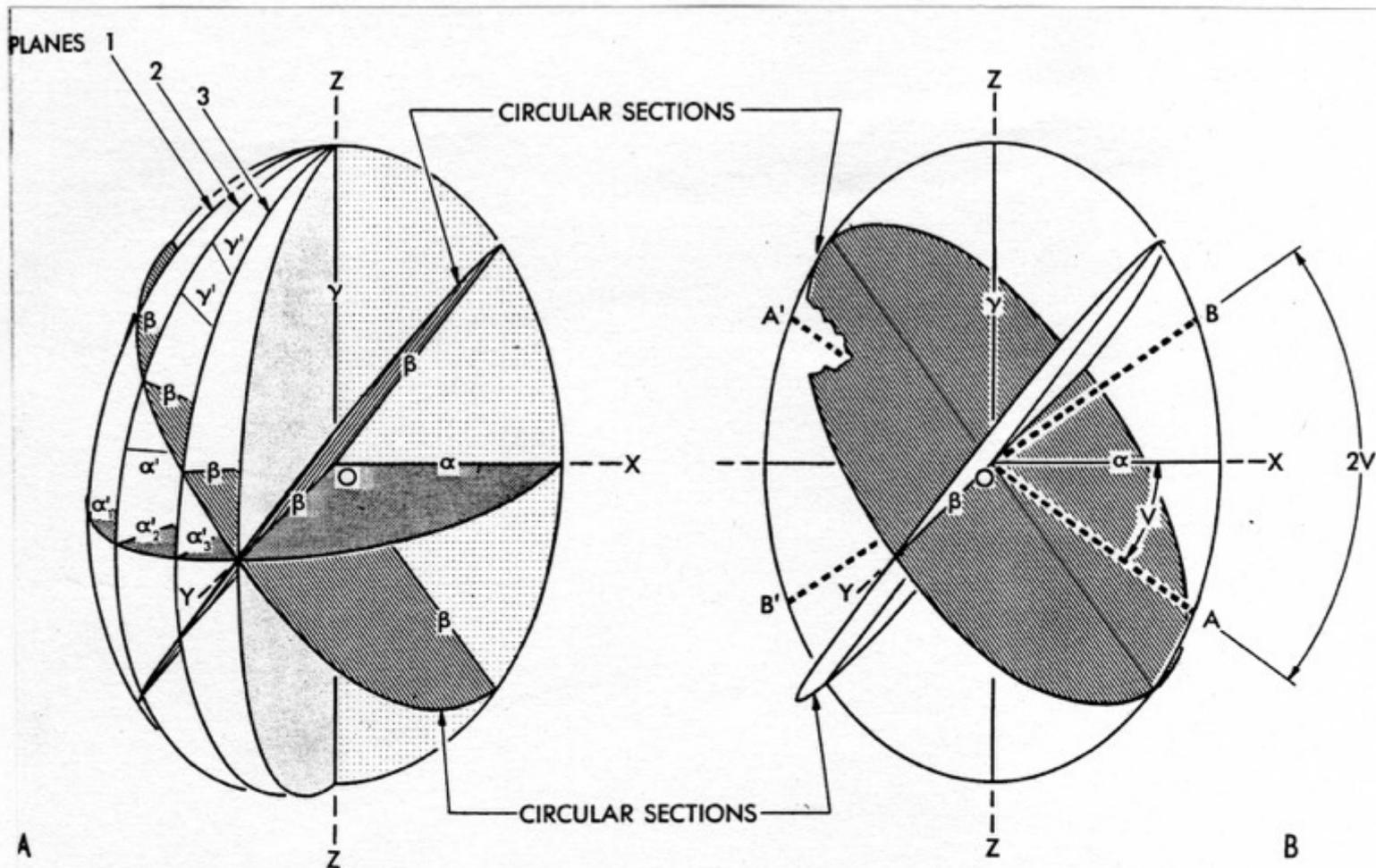
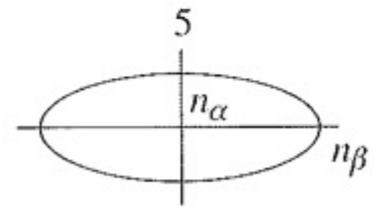
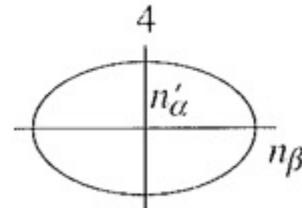
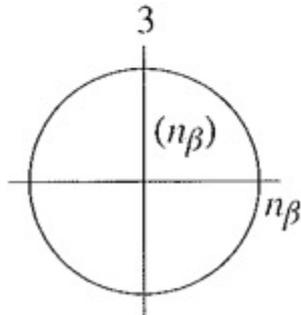
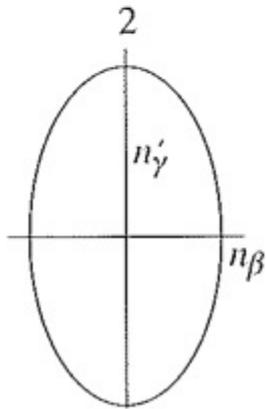
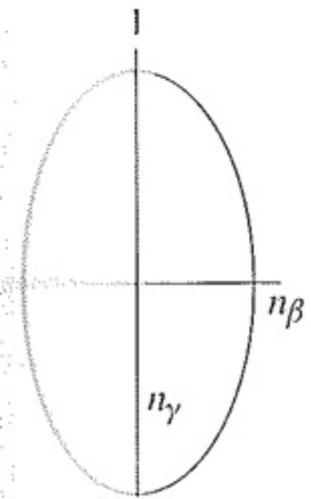
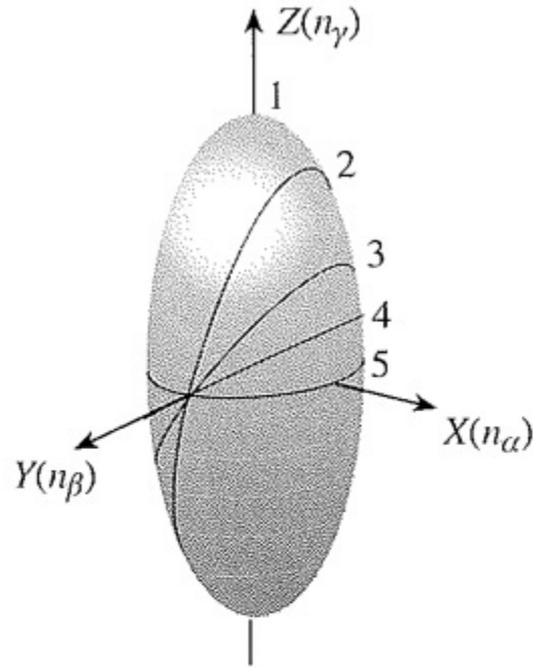


Fig. 9-2. (A) Variation of refractive index in a biaxial crystal as shown by ellipses (whose radii are proportional in length to the crystal's refractive index for light vibrating parallel to them). Planes 1, 2, and 3 are typical of the numerous ellipses that could be drawn to hinge on ZZ . All such ellipses contain one radius equal to β in length, these radii lying in the same planes (ruled). These planes, the circular sections, intersect in principal axis γ . (B) The biaxial indicatrix; that is, simply an imaginary three-dimensional ellipsoid whose radii are proportional to the crystal's refractive indices for light vibrating parallel to them. The normals to the circular sections, AA' and BB' , are the two optic axes.

$$\gamma > \beta > \alpha$$



+

-

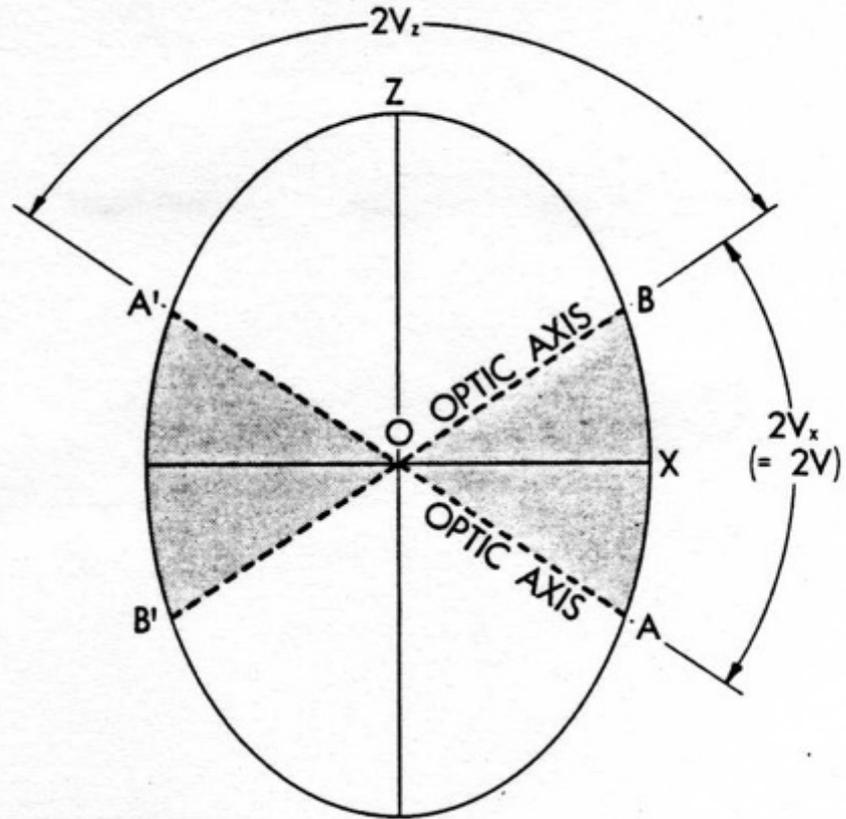
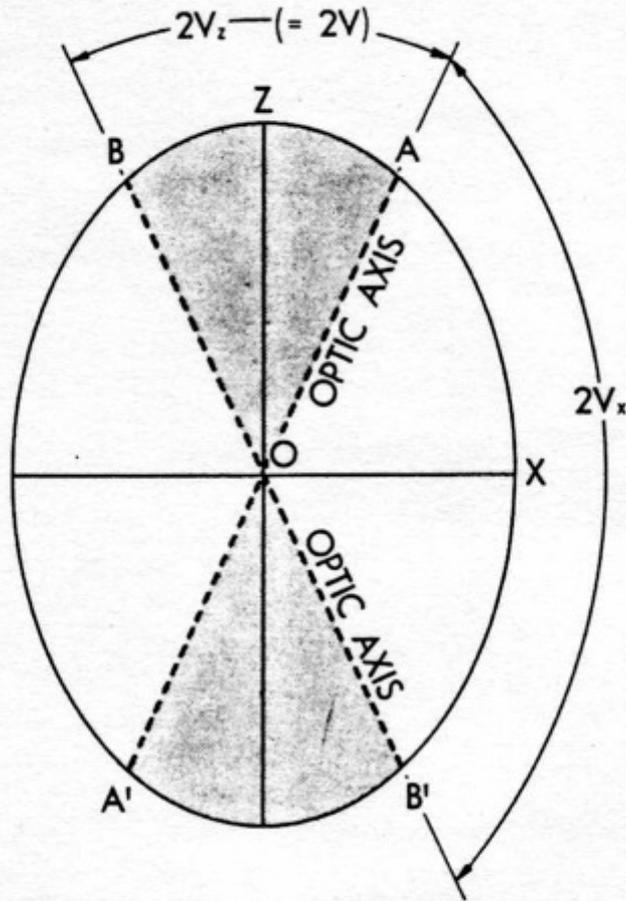


Fig. 9-4. Relationship between $2V_x$ and $2V_z$. Note that $2V$ equals $2V_x$ or $2V_z$, whichever is smaller. The dashed lines represent the optic axes.

+

-

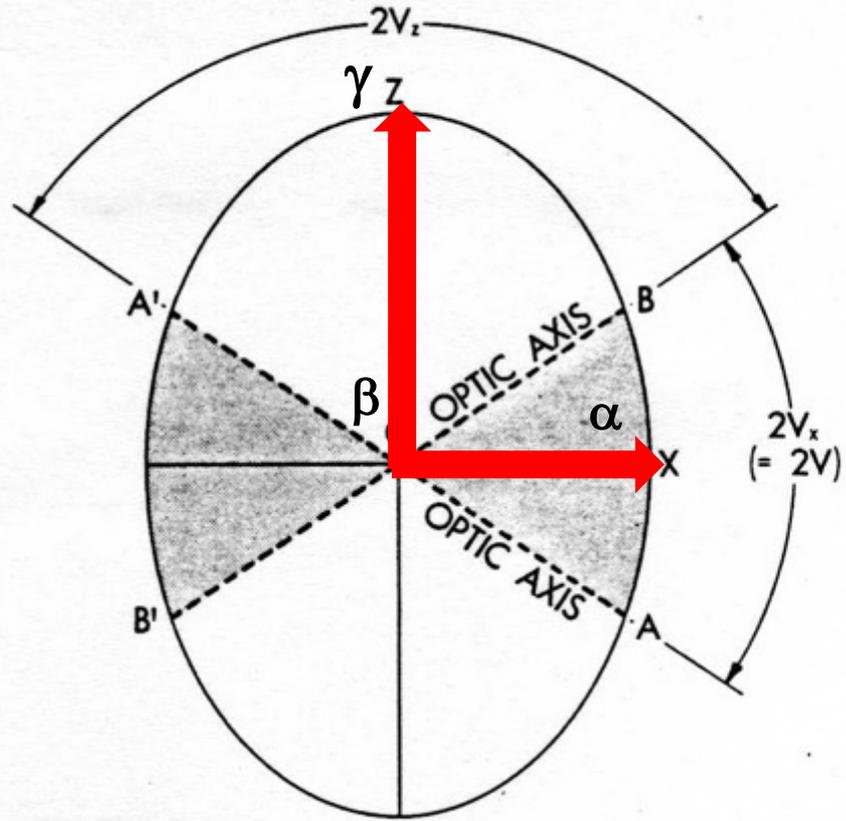
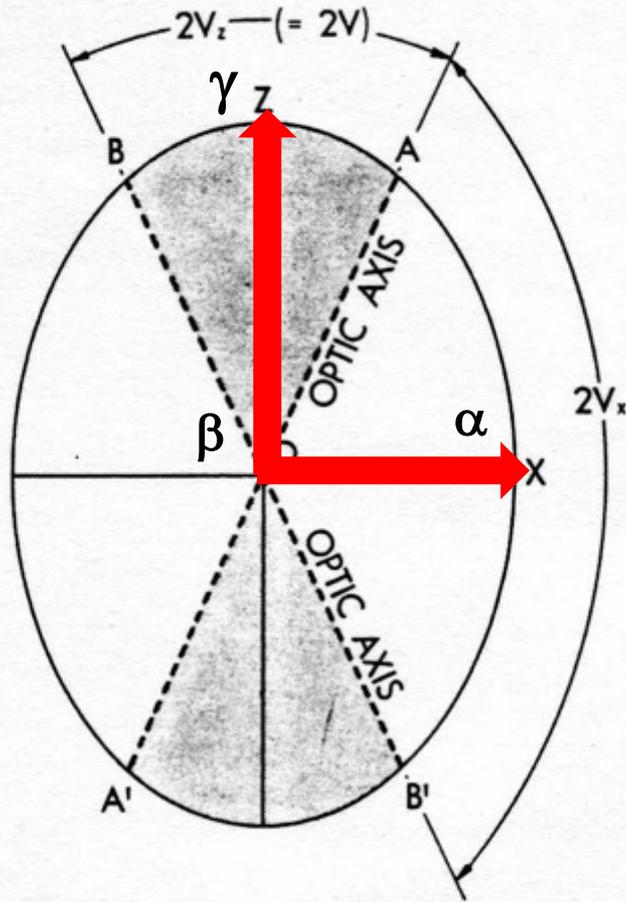


Fig. 9-4. Relationship between $2V_x$ and $2V_z$. Note that $2V$ equals $2V_x$ or $2V_z$, whichever is smaller. The dashed lines represent the optic axes.

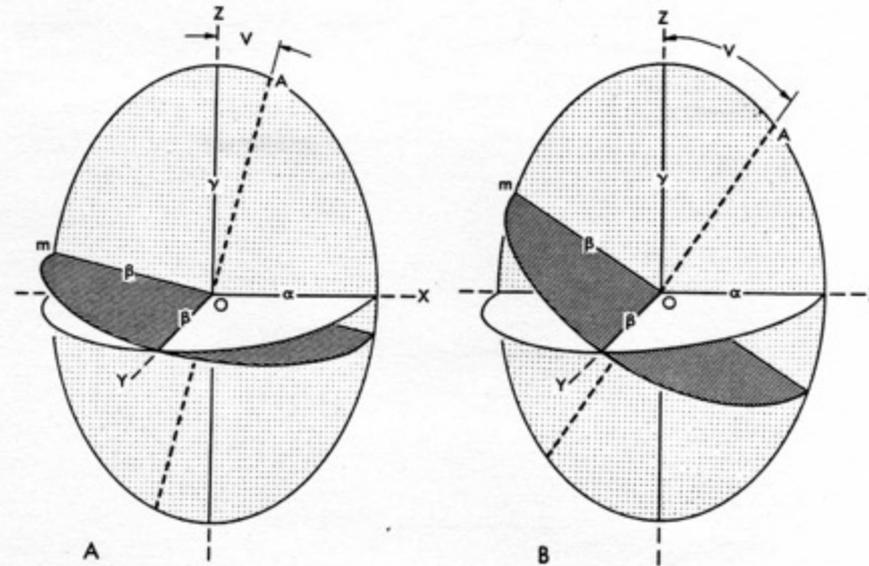


Fig. 9-5. The variation of $2V$ in four crystals all possessing equal values of α and γ but, from (A) to (D), increasing values of β . For simplicity only one circular section (closely ruled) and one optic axis (OA) are drawn. Note the attendant increase in $2V$ from (A) to (C). With increase in β beyond that in (C), the optic sign becomes negative. Note that V_x increases continuously from (A) to (D).

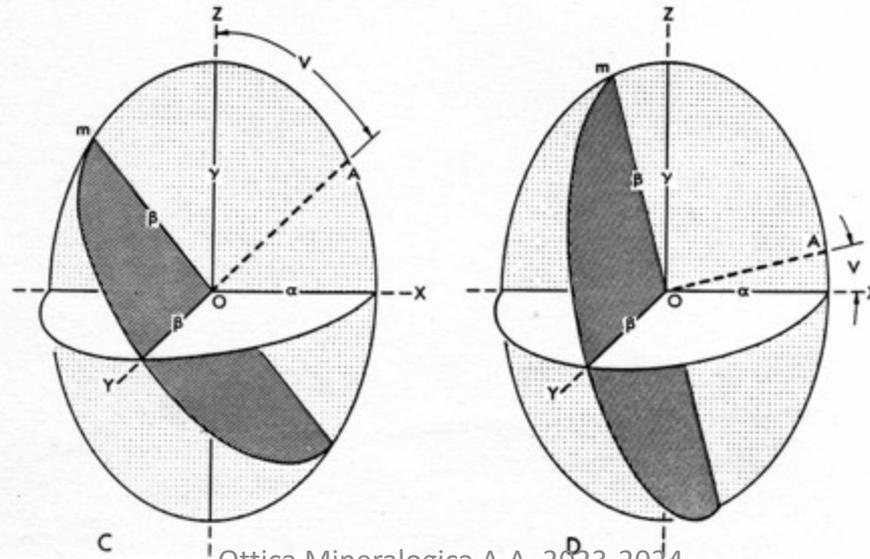
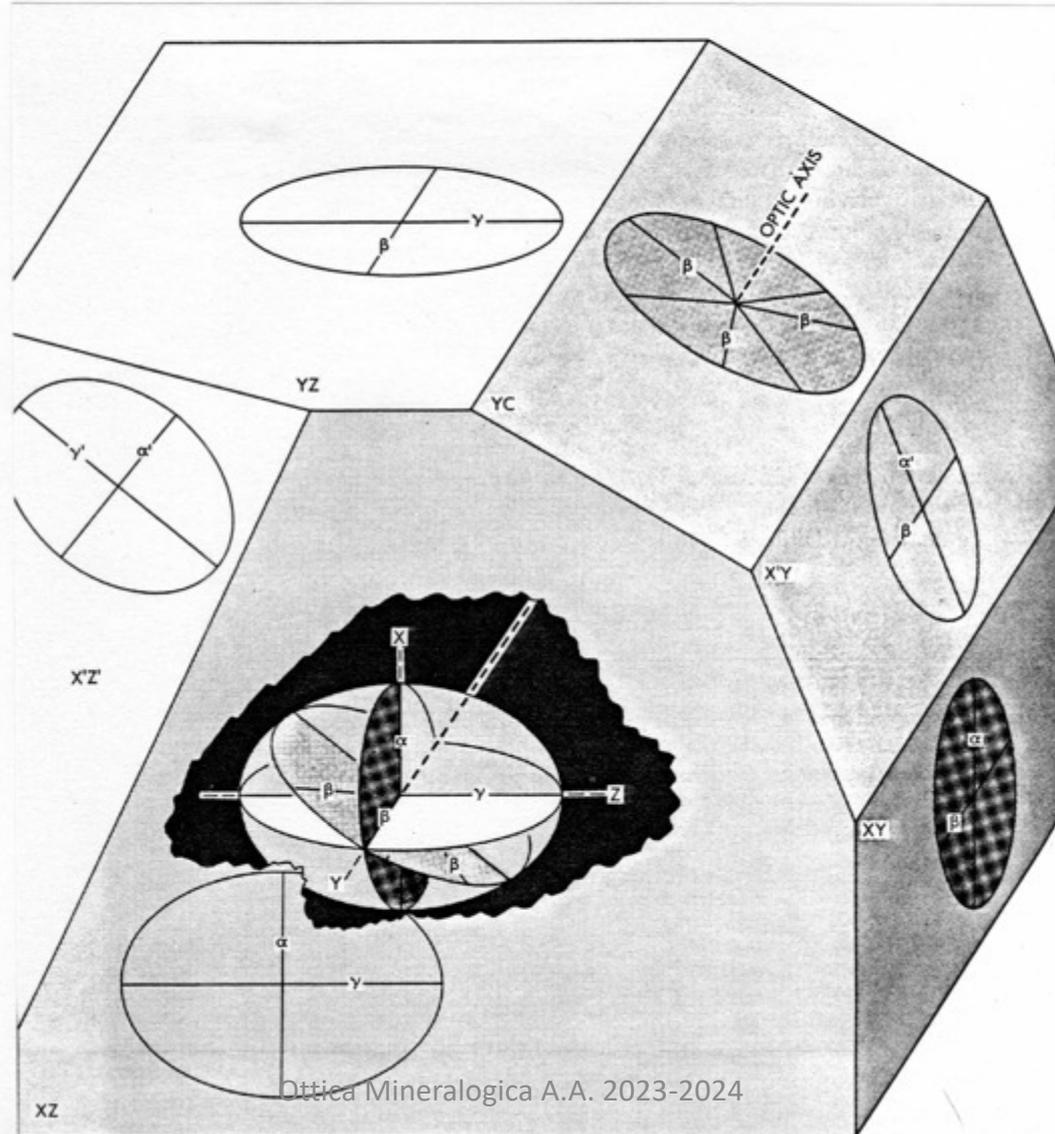


Fig. 9-9A. The vibration directions, W_N and W_n , that are associated with wave normal OW , as obtained by the Biot-Fresnel rule. (OA and OB represent the two optic axes.)



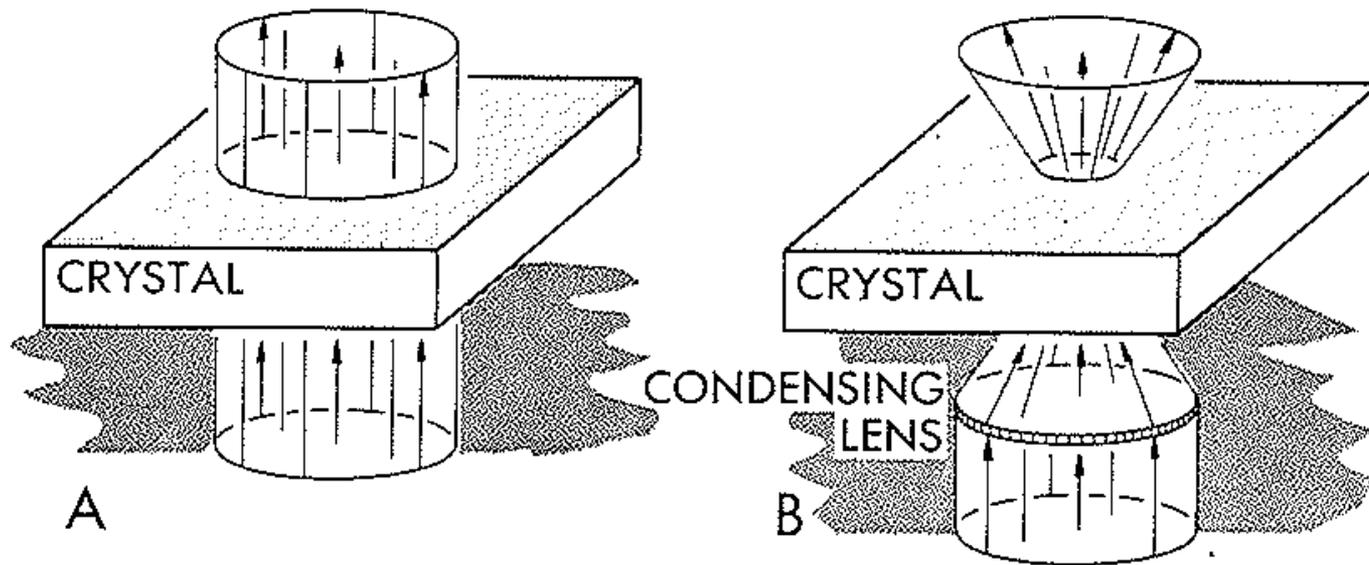


Fig. 7-10. Comparison of the ray paths for orthoscopic illumination (A) and conosopic illumination (B). For the actual situation the rays shown in (A) would be slightly convergent. They become increasingly parallel, however, as the apertures are decreased (for example, by closing down the iris diaphragm or inserting a lower power lens).

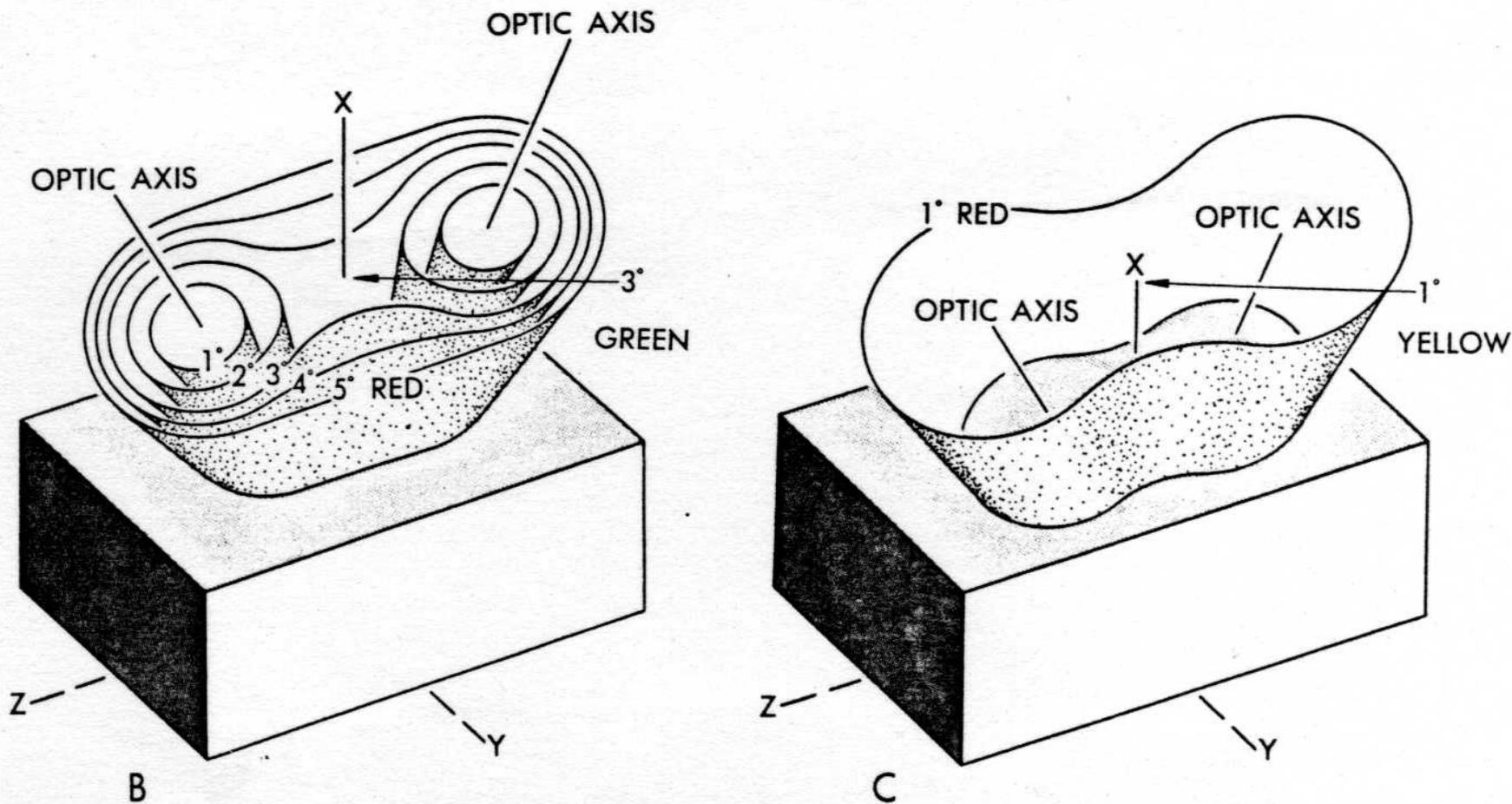
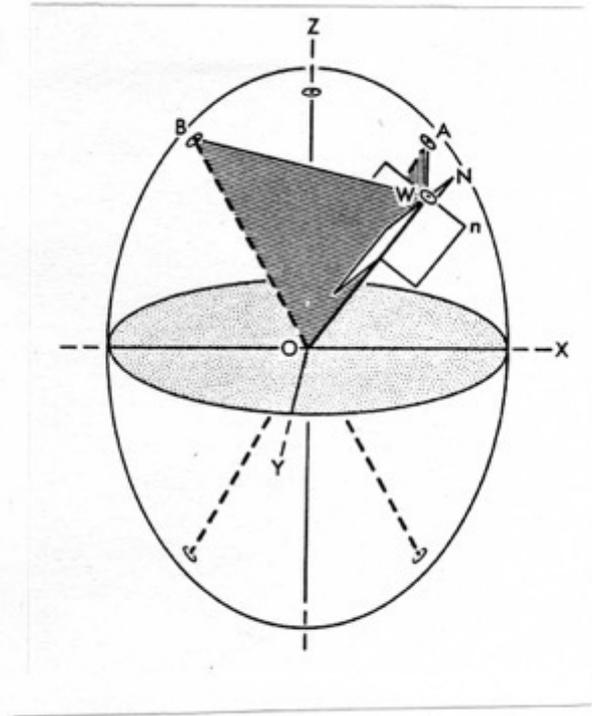


Fig. 9-15B-C. (B) Surfaces of equal retardation above a crystal of moderate to high birefringence. (C) Same for crystal of low birefringence.

Fig. 9-8. A given wave normal direction, OW , is shown in respect to ON and On , the only two vibration or privileged directions possibly associable with it; angles WON and WOn are therefore 90 degree angles. Note that ON and On are the major and minor axes of the ellipse (stippled) obtained by passing a plane (perpendicular to OW) through the indicatrix. Each of these vibration directions, in conjunction with OW , defines a plane that also cuts the indicatrix in an ellipse (shaded). Ray paths OR_1 or OR_2 , the only two ray paths associable with wave normal OW , lie within these ellipses, being radii of the ellipse conjugate to the vibration direction.



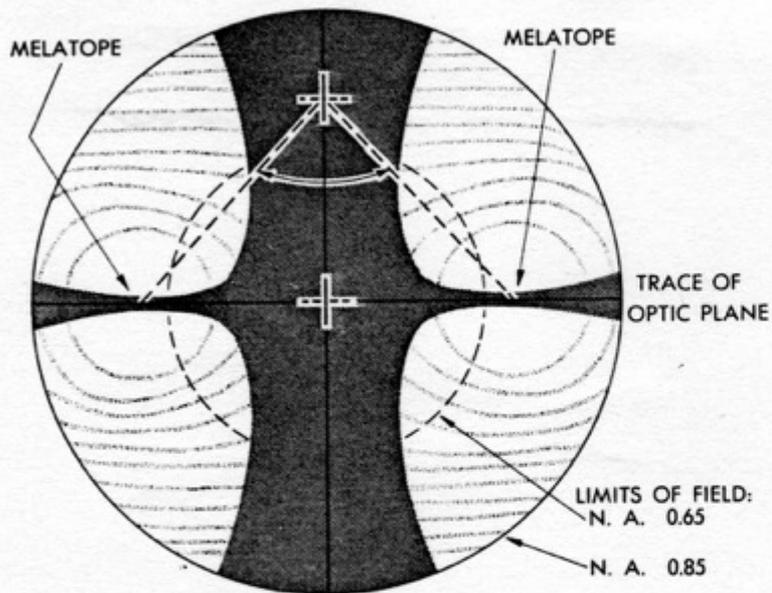


Fig. 9-16B. Fig. 9-16A as seen if the microscope stage is rotated 45 degrees counterclockwise. Extinction occurs in the areas where rays emerge that vibrate parallel to the polarizer. The dashed circle marks the limits of the field of view if an objective of N. A. 0.65 is used instead of one of N. A. 0.85.

+

-

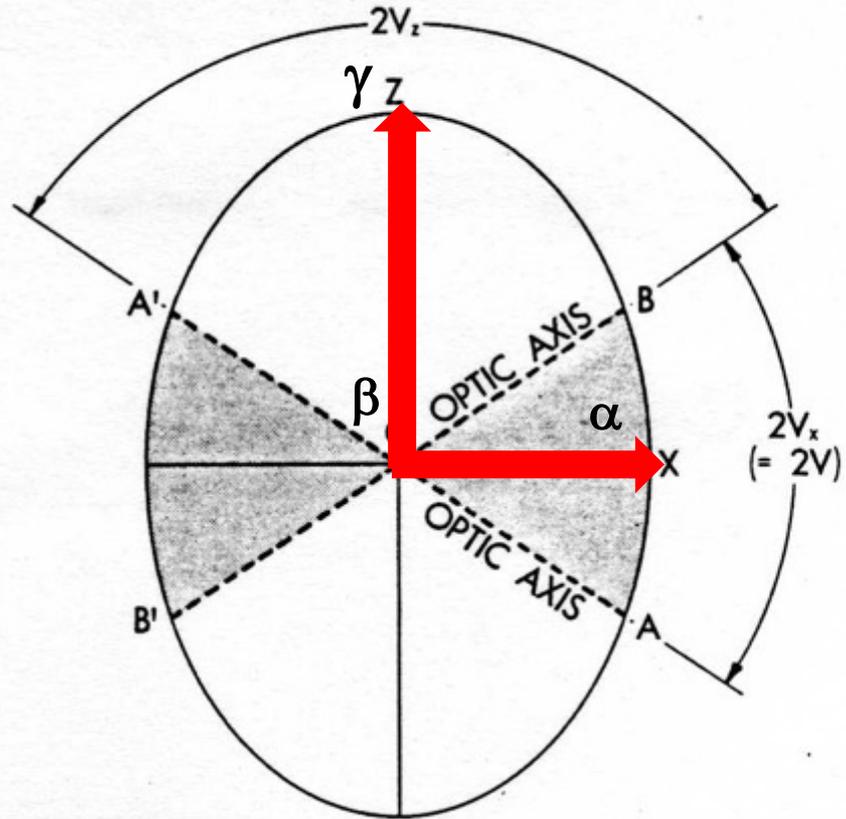
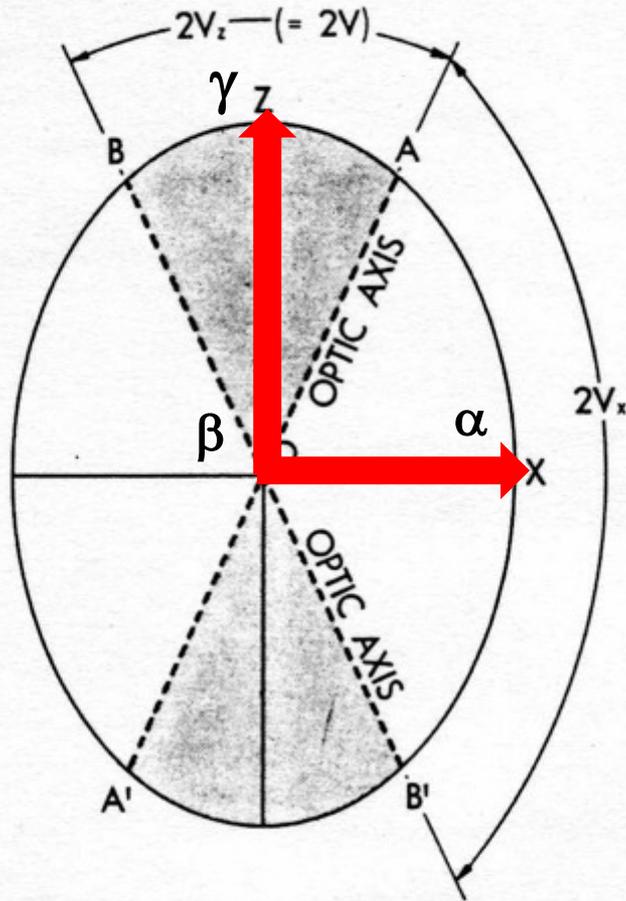
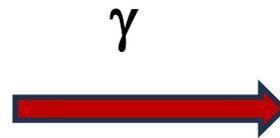
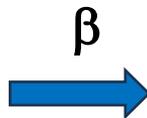
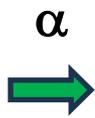
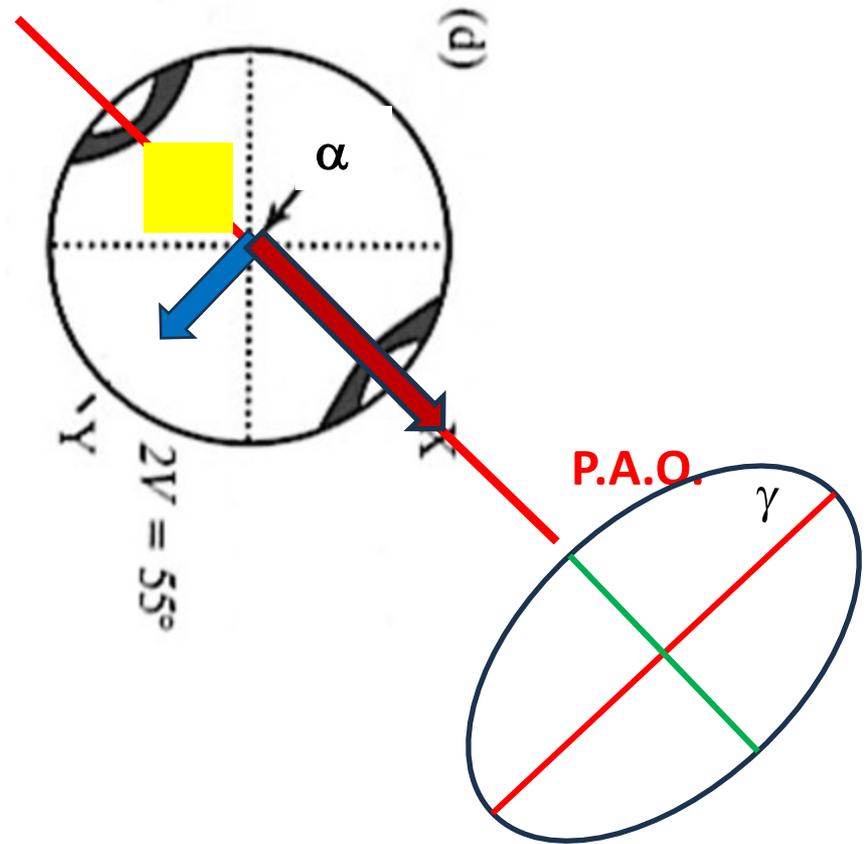
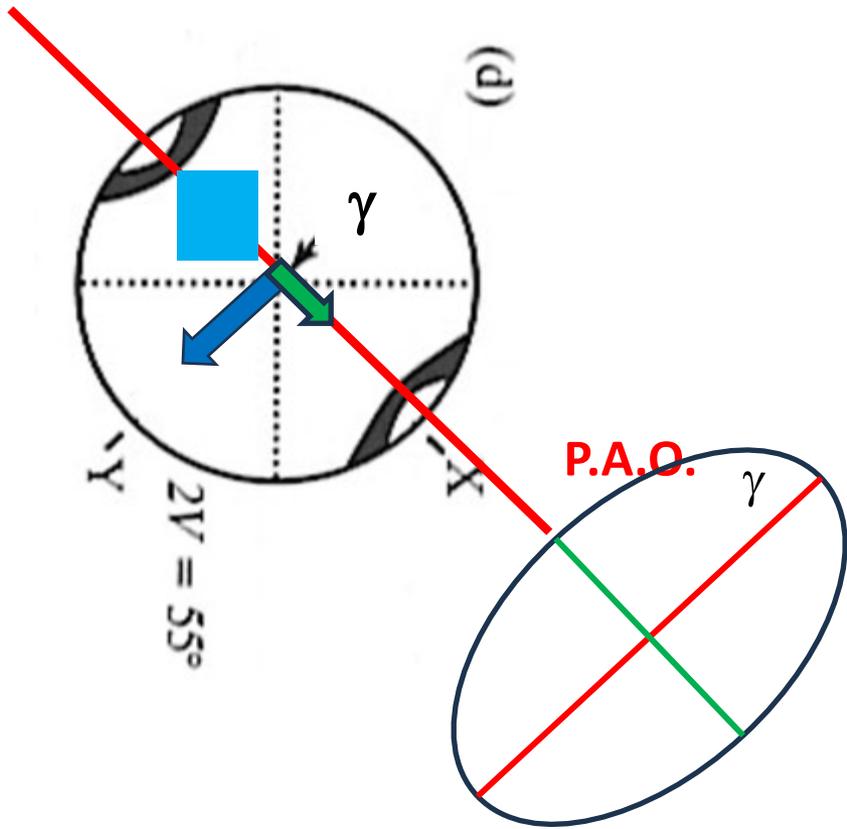
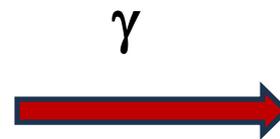
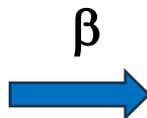
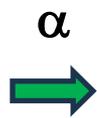
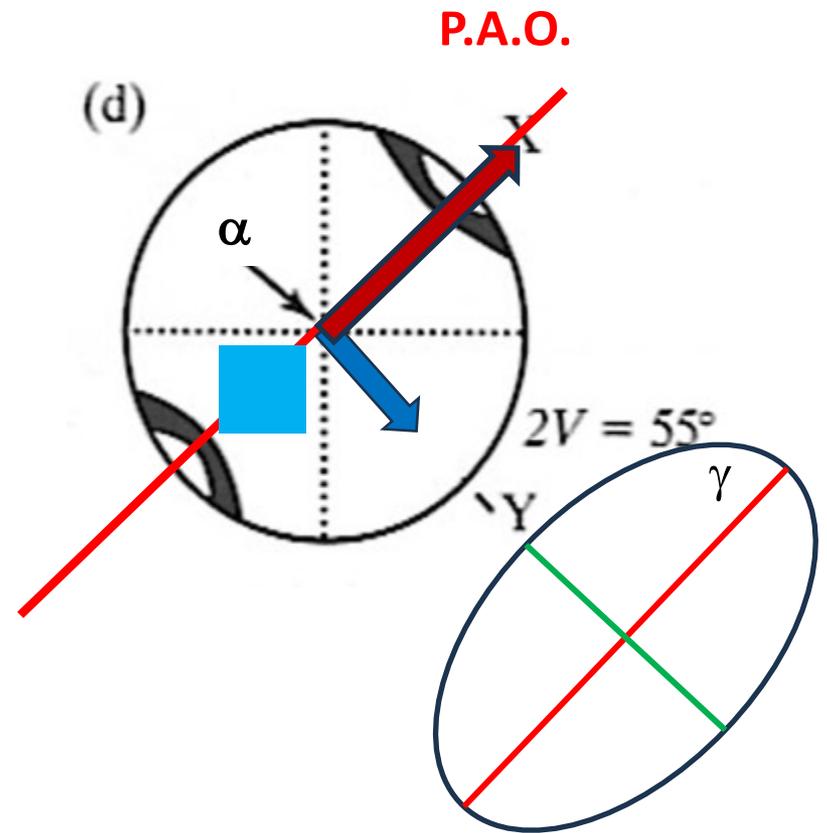
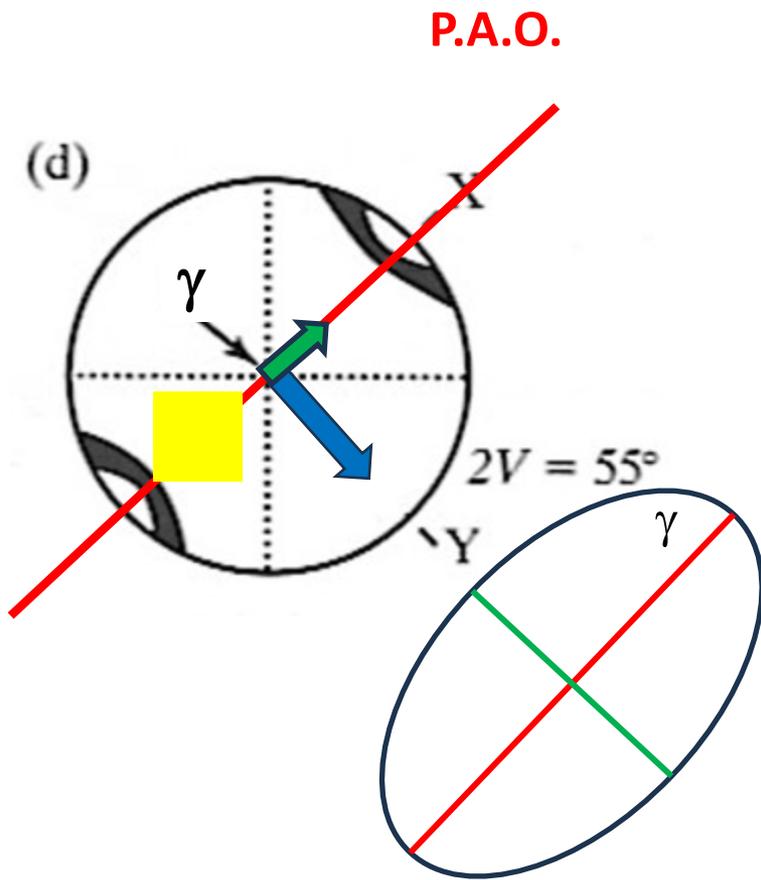
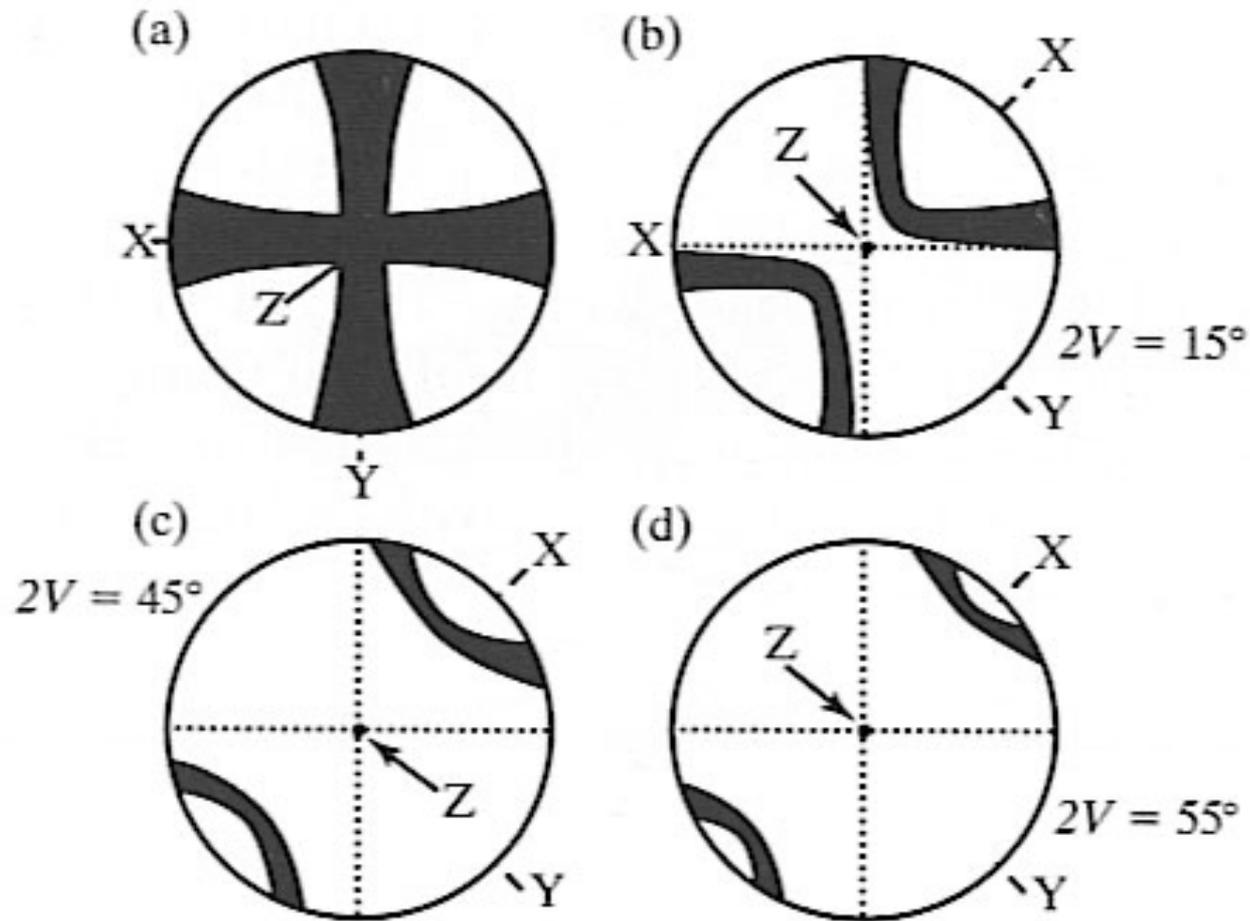


Fig. 9-4. Relationship between $2V_x$ and $2V_z$. Note that $2V$ equals $2V_x$ or $2V_z$, whichever is smaller. The dashed lines represent the optic axes.





Sezione normale BA, stima del $2V$ dalla separazione delle isogire



Sezione normale AO, stima del $2V$ dalla curvatura dell'isogira

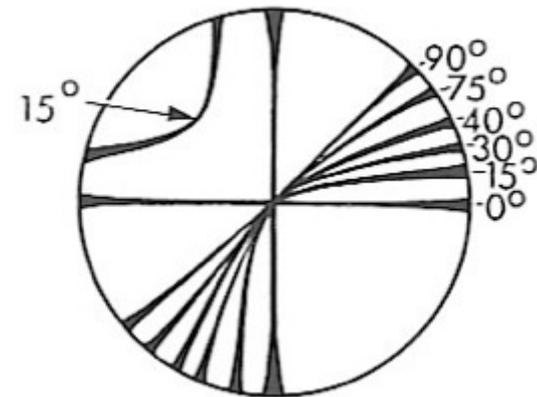
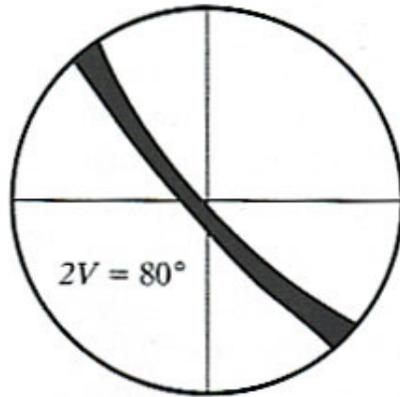
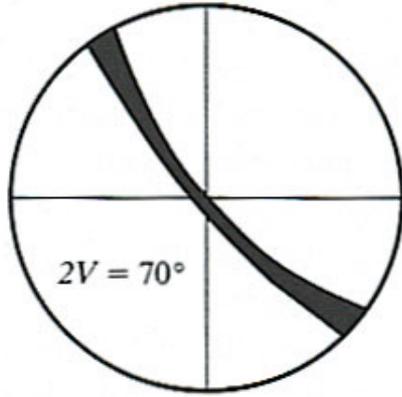
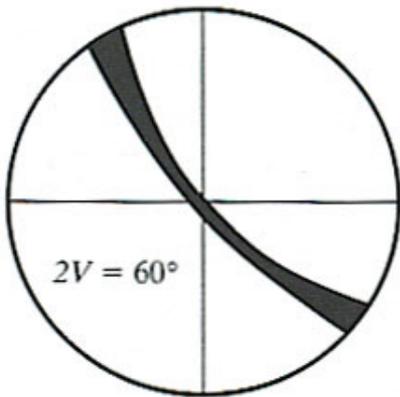
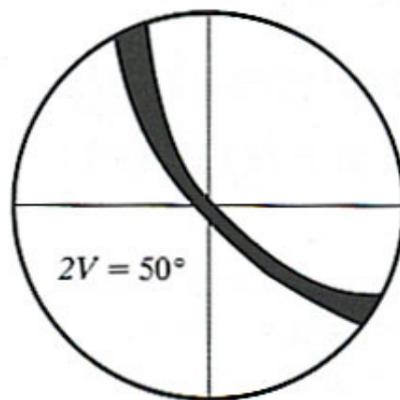
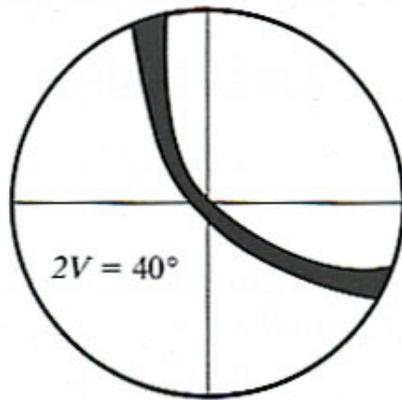
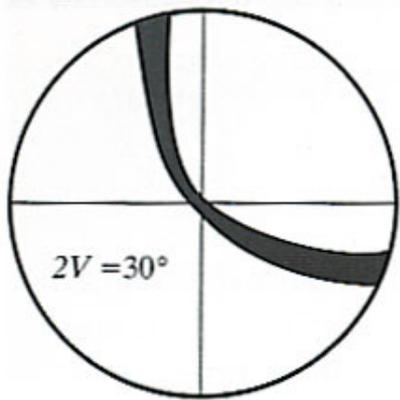
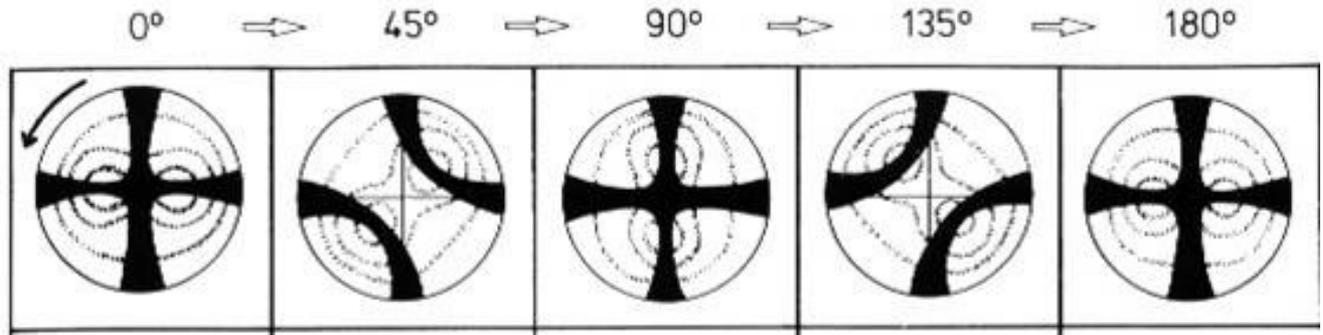
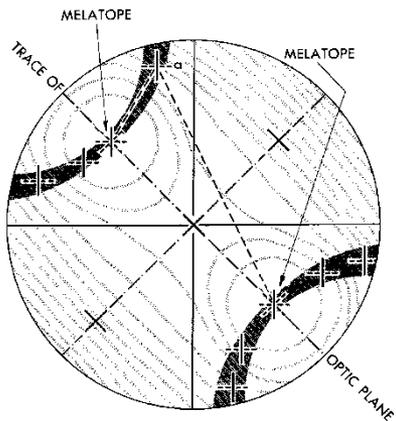


FIGURA D'INTERFERENZA (CONOSCOPICA) : CRISTALLI BIASSICI

SEZIONE ORTOGONALE alla BISETTRICE ACUTA



In diversi momenti ruotando il piatto del microscopio

SEGNO OTTICO

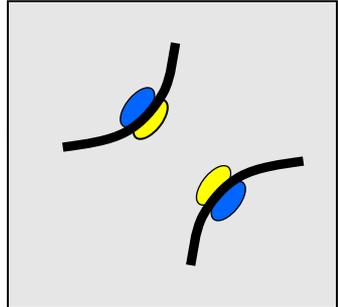
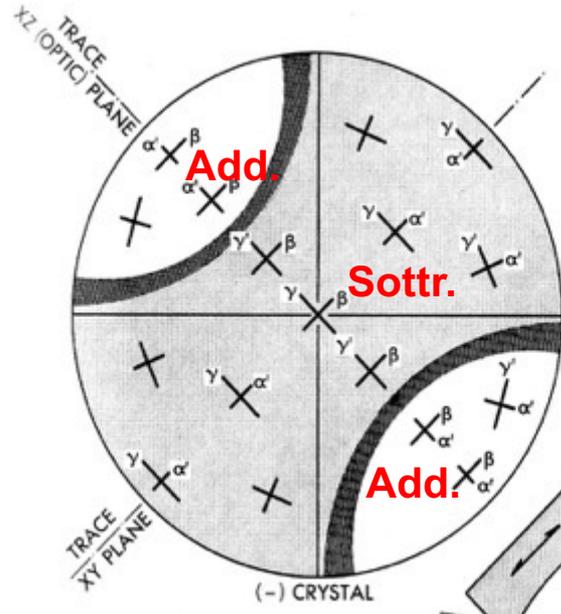
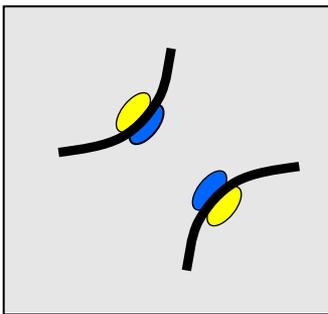
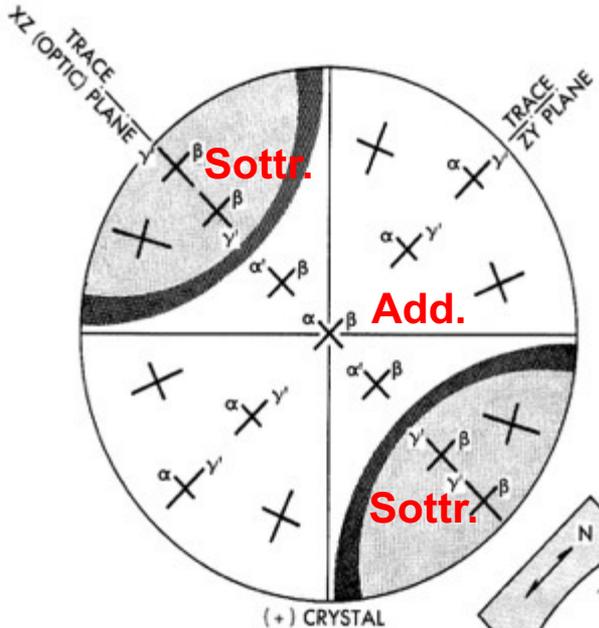
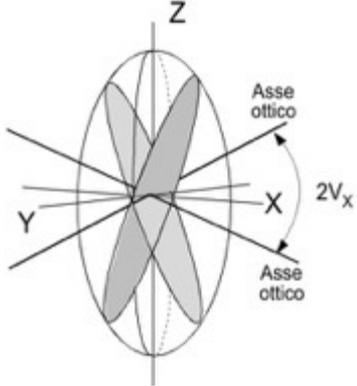
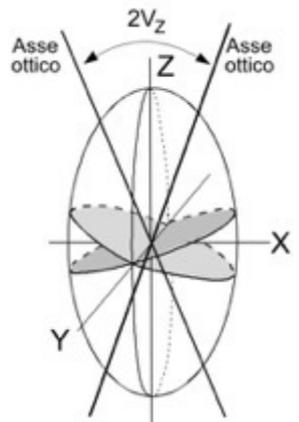
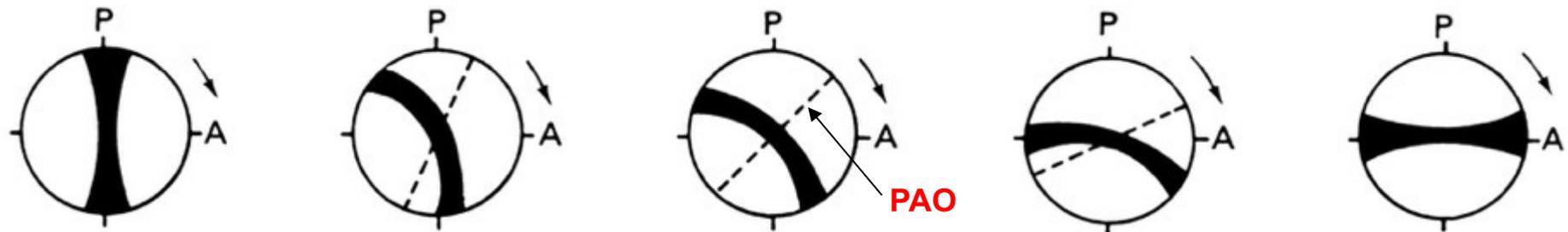
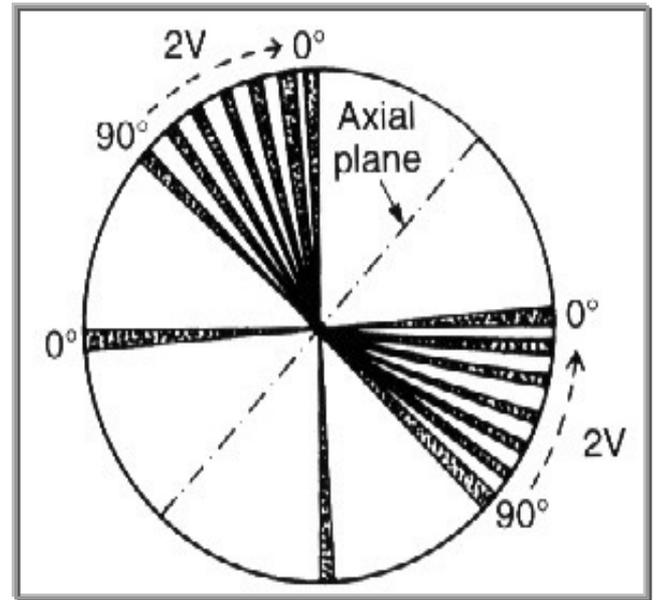
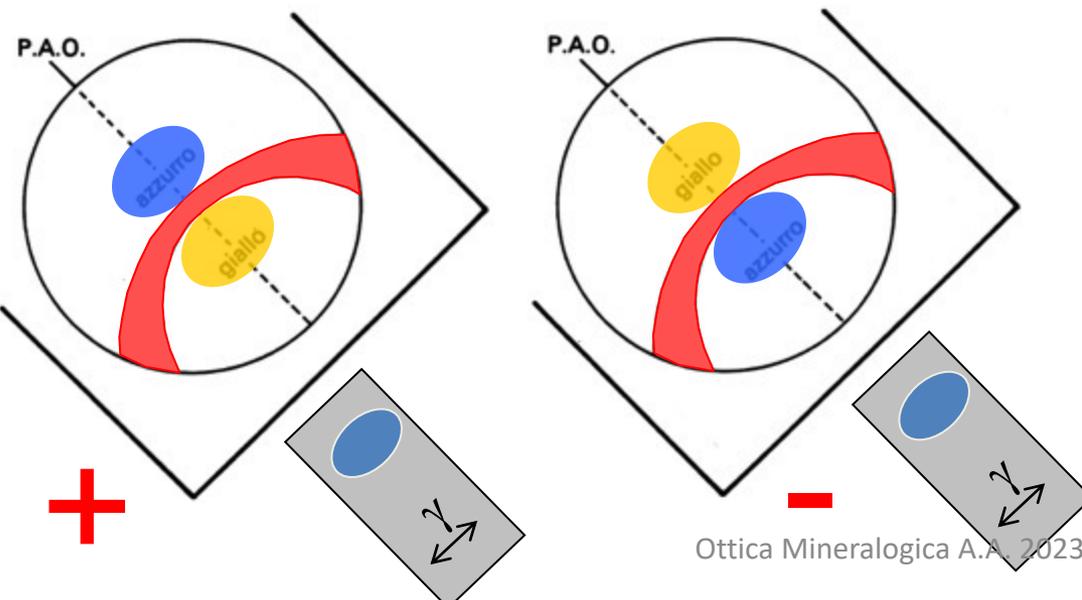
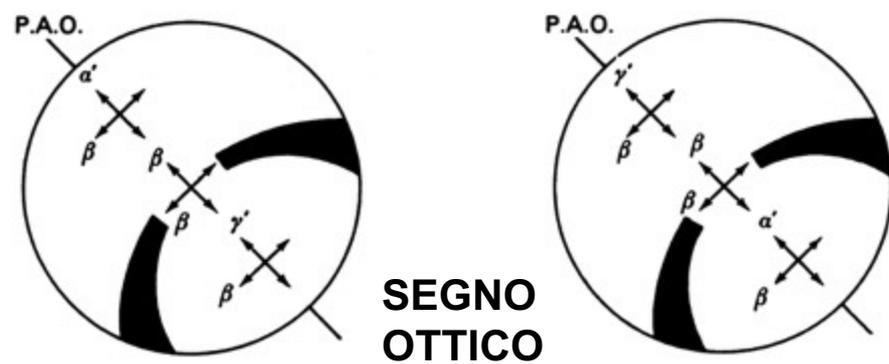


FIGURA D'INTERFERENZA (CONOSCOPICA) : CRISTALLI BIASSICI

SEZIONE ORTOGONALE a AO



In diversi momenti ruotando il piatto del microscopio.
 Quando il PAO (linea tratteggiata) è posto a 45° rispetto ai Nicols, l'isogira rivolge sempre la convessità verso la bisettrice acuta



Stima del 2V dalla curvatura dell'isogira per PAO a 45° dai Nicols. È illustrata la curvatura ad intervalli di 15°

SCHEMA PER L'IDENTIFICAZIONE DI UN MINERALE

Nicol //

Minerale da identificare

forma

opaco

trasparente

rilievo

colore, pleocroismo

sfaldature

Nicol X

isotropo

anisotropo

birifrangenza

estinzione

Conosc.

uniassico

biassico

2V

+ □

+ □ -