

# Cristallografia Ottica

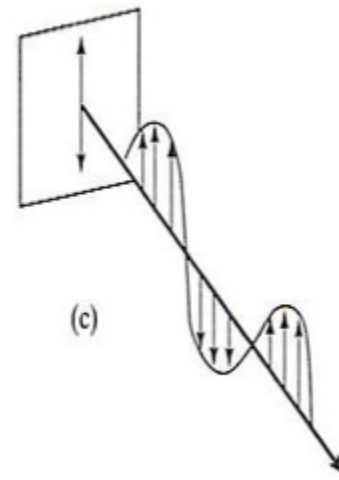
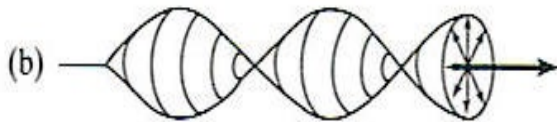
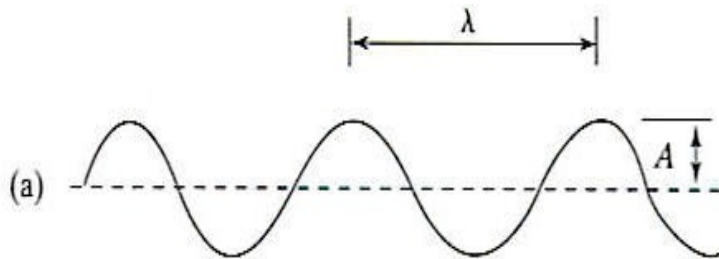
Figure e testi tratti da:

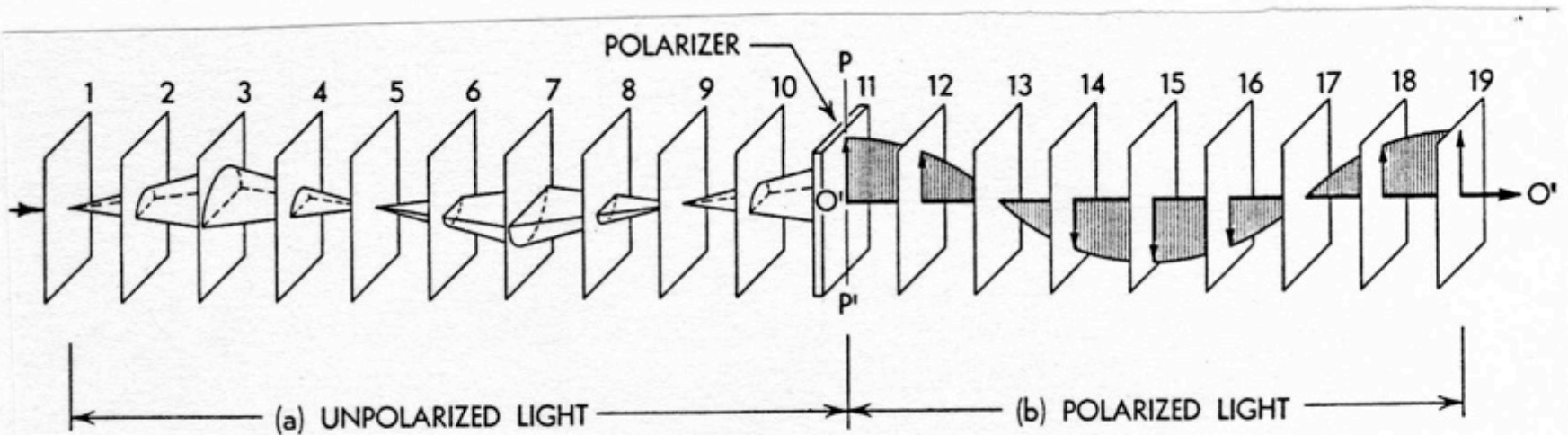
Bloss: Introduction to the methods of Optical Cristallography.

Wenk-Bulakh: Minerals, their constitution and origin.

# 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

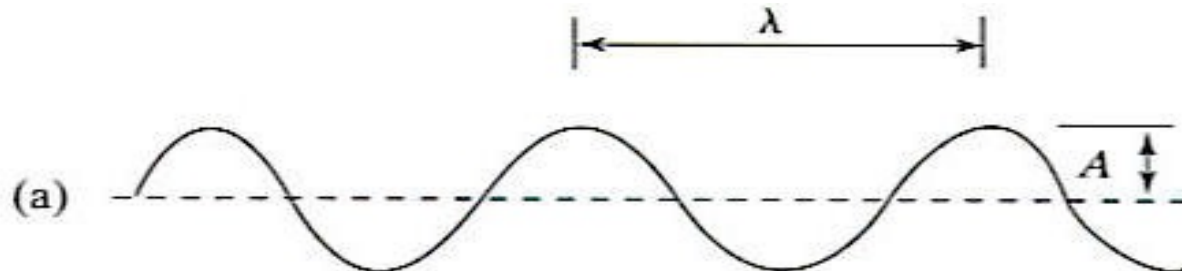
**Lunghezza d'onda ( $\lambda$ )** - distanza tra due picchi d'onda; si misura in angstroms ( $\text{\AA}$ ); definisce il colore della luce.

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

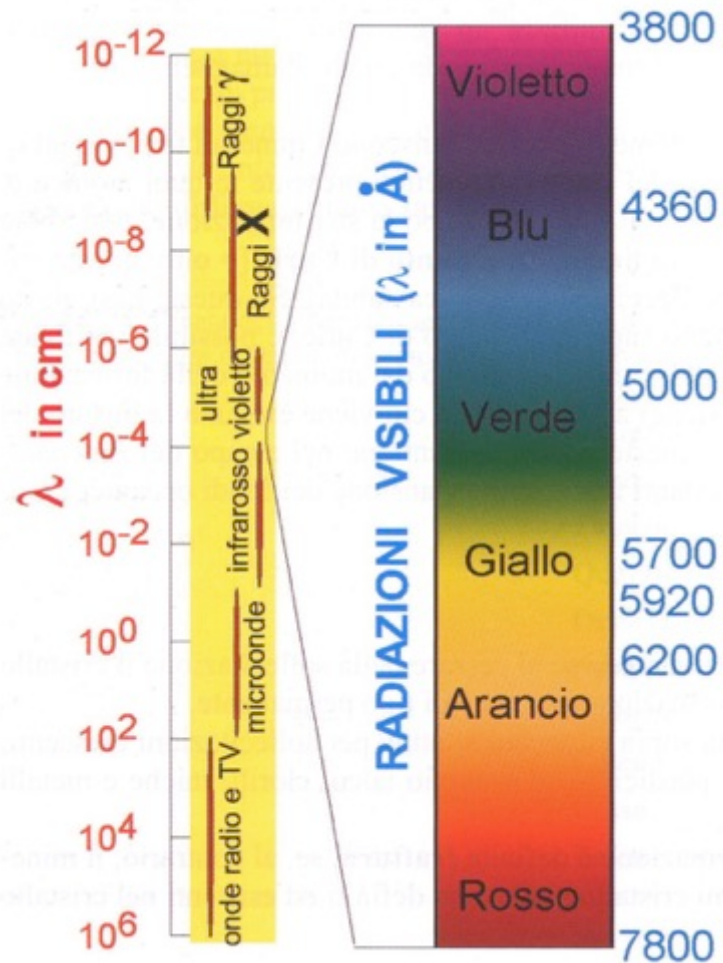
**Frequenza ( $f$ )** - numero di onde luminose che passano per un punto fisso per secondo; si misura in cicli per secondo.

**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, una diminuzione della velocità della luce riflette una diminuzione proporzionale della sua lunghezza d'onda.



## SPETTRO ELETTRMAGNETICO



$\lambda$  = lunghezza d'onda

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

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

$\lambda_{\text{rosso}} = 0.00078 \text{ mm}$

$\lambda_{\text{violetto}} = 0.00038 \text{ mm}$

## 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**:

$$n = c/v$$

$n_{\text{aria}} = 1$

$n_{\text{mezzi}} \text{ sempre } > 1$

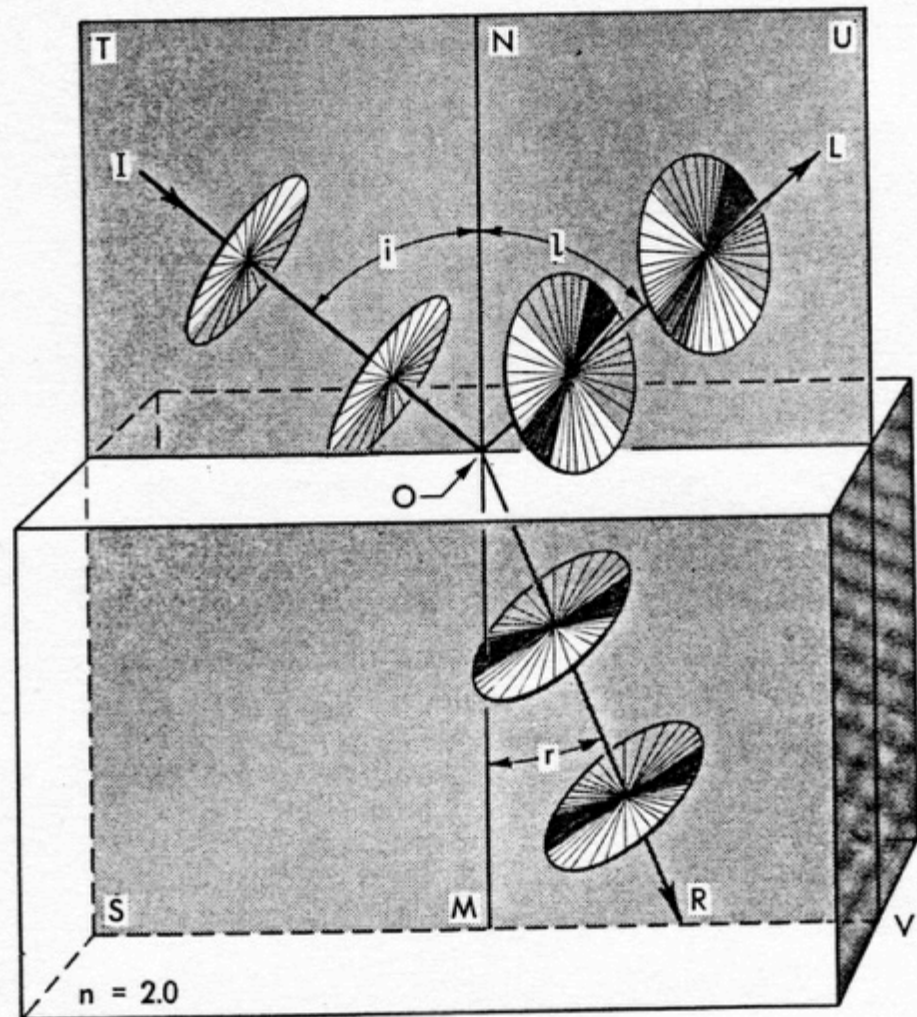


Fig. 2-1. An unpolarized ray,  $IO$ , incident in air upon the upper surface of a transparent glass block of index 2.0, forms a reflected ray,  $OL$ , and a refracted ray,  $OR$ . All the ray paths, as well as the angles of incidence ( $i$ ), of reflection ( $l$ ), and of refraction ( $r$ ), lie within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



## Angolo critico e total riflessione.

Scriviamo la legge di Snell nel seguente modo:

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

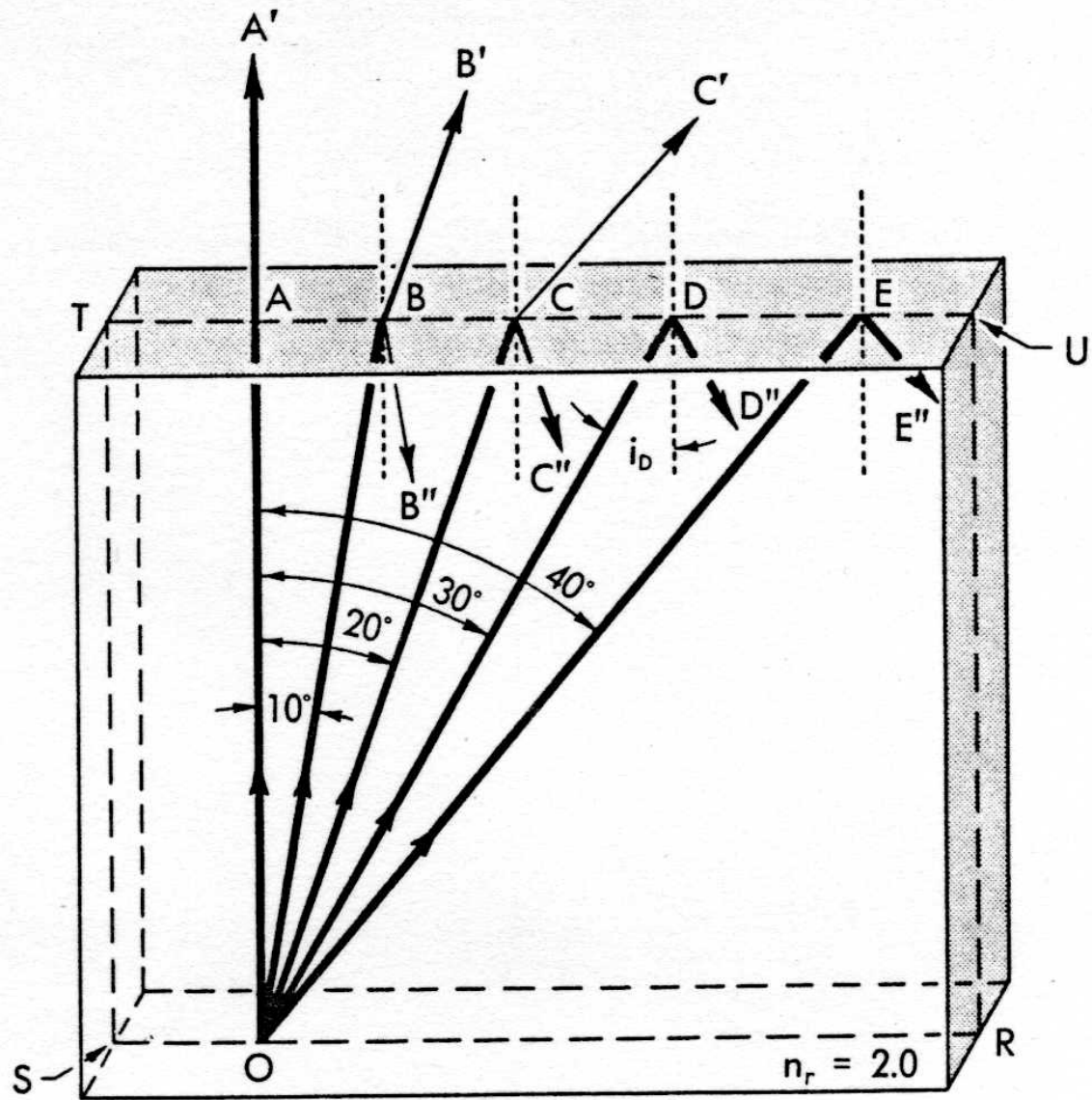
Se il mezzo incidente ha indice di rifrazione inferiore al mezzo di rifrazione ( $n_i < n_r$ ) l'angolo di rifrazione si avvicina alla normale di separazione dei due mezzi.

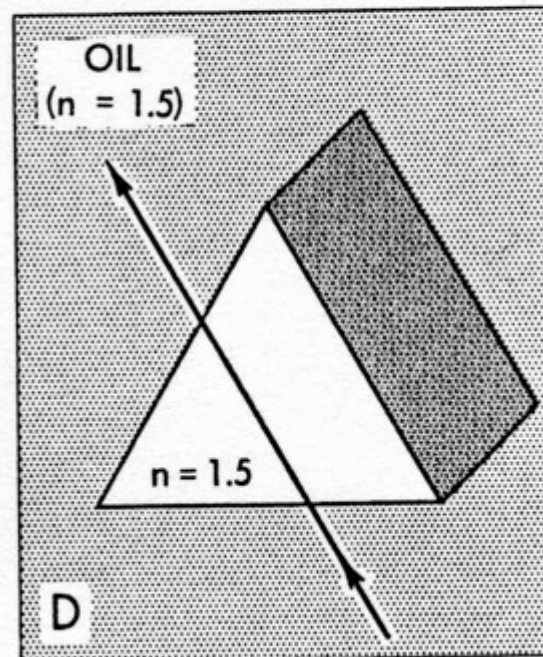
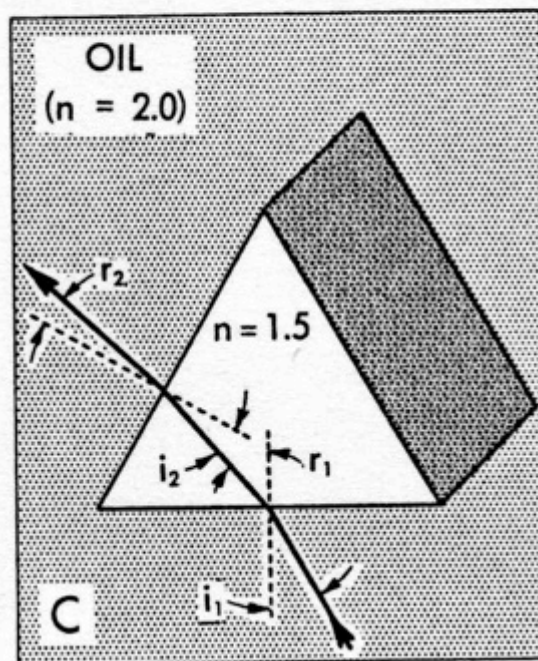
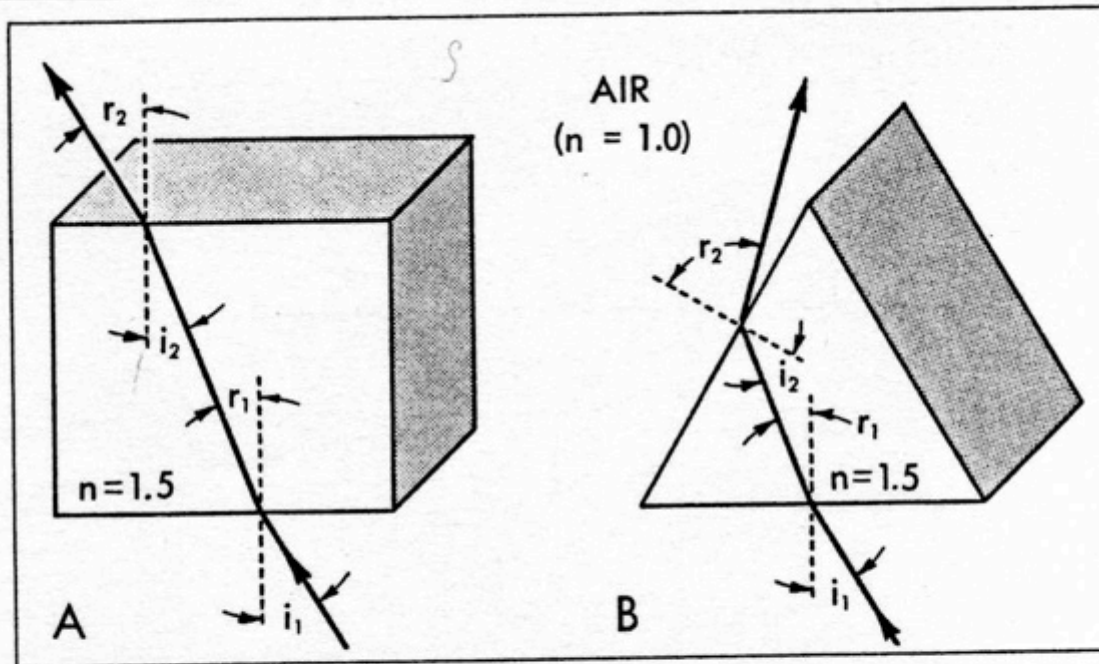
Se il mezzo di incidenza ha indice di rifrazione superiore al mezzo di rifrazione ( $n_i > n_r$ ), il raggio rifratto si allontana dalla normale di separazione dei due mezzi.

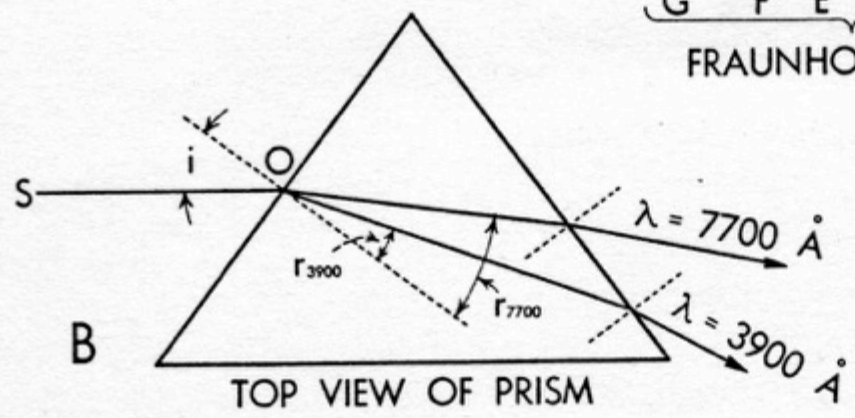
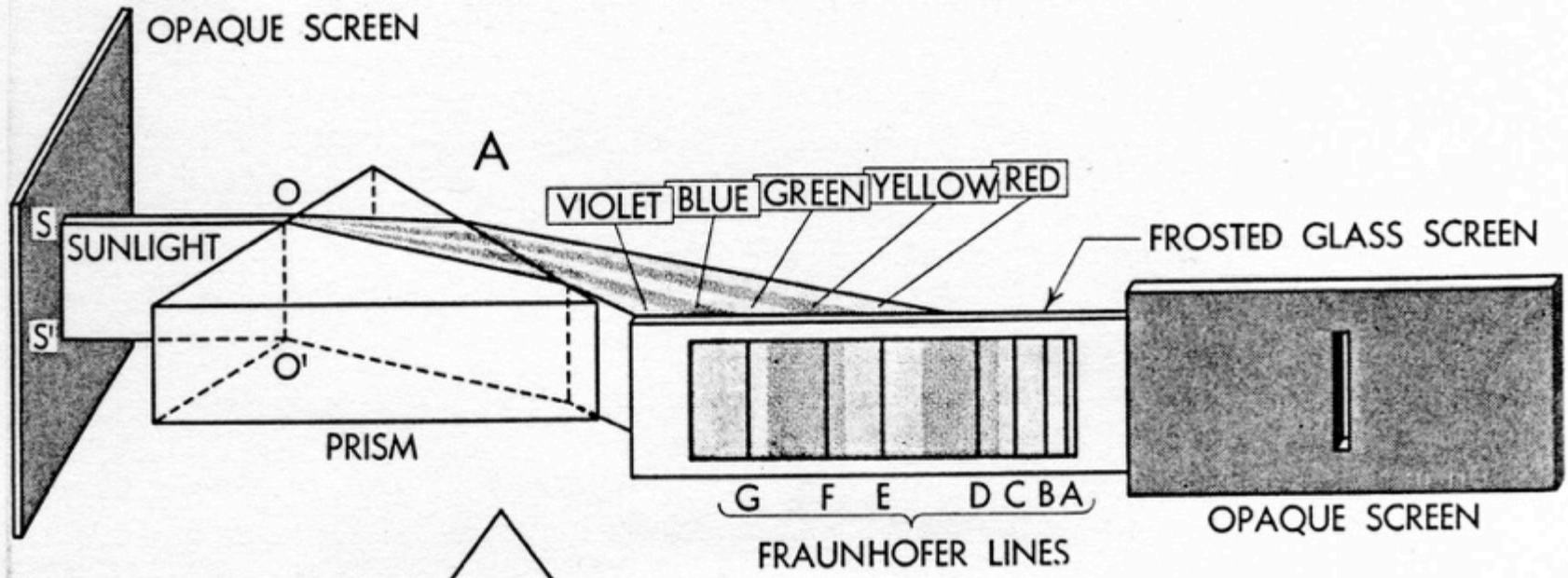
Ad esempio se  $n_i=2$  e  $n_r=1$  per  $i=30$   $r=90^\circ$ .

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



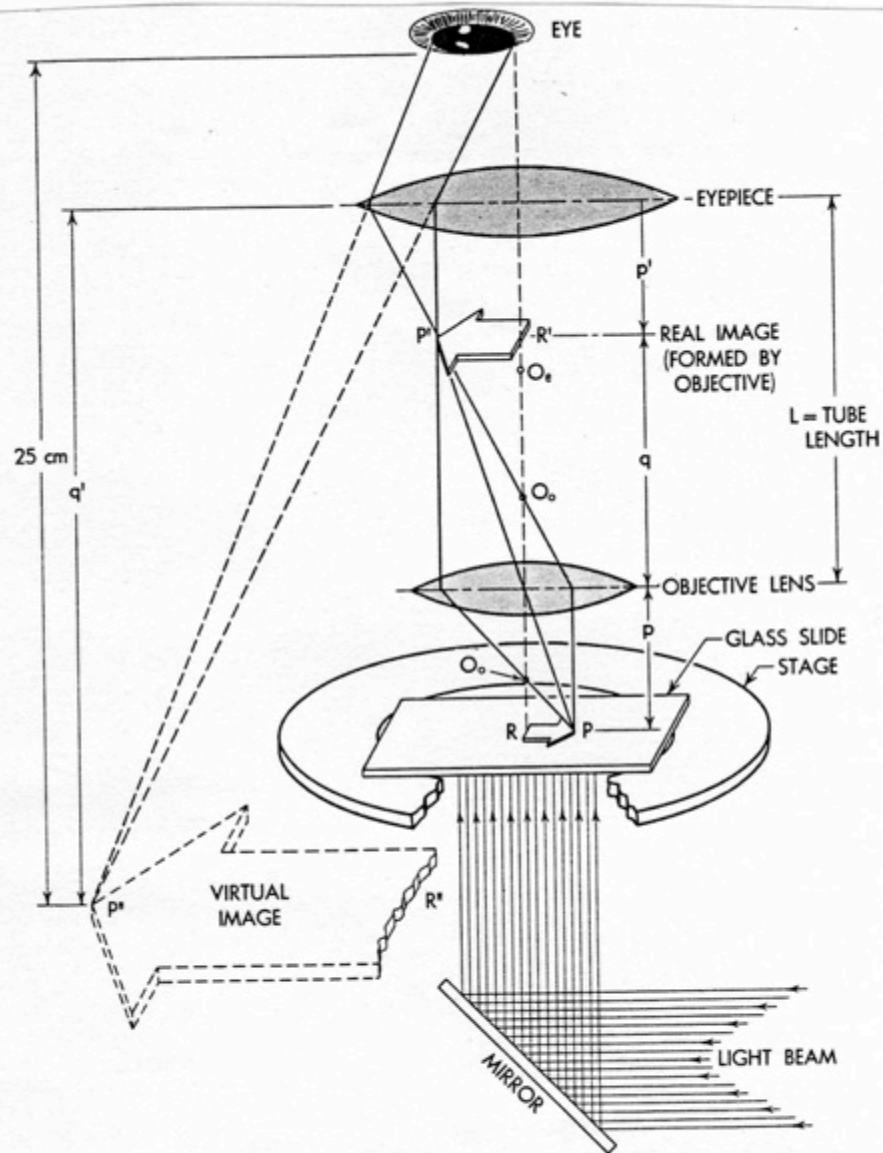




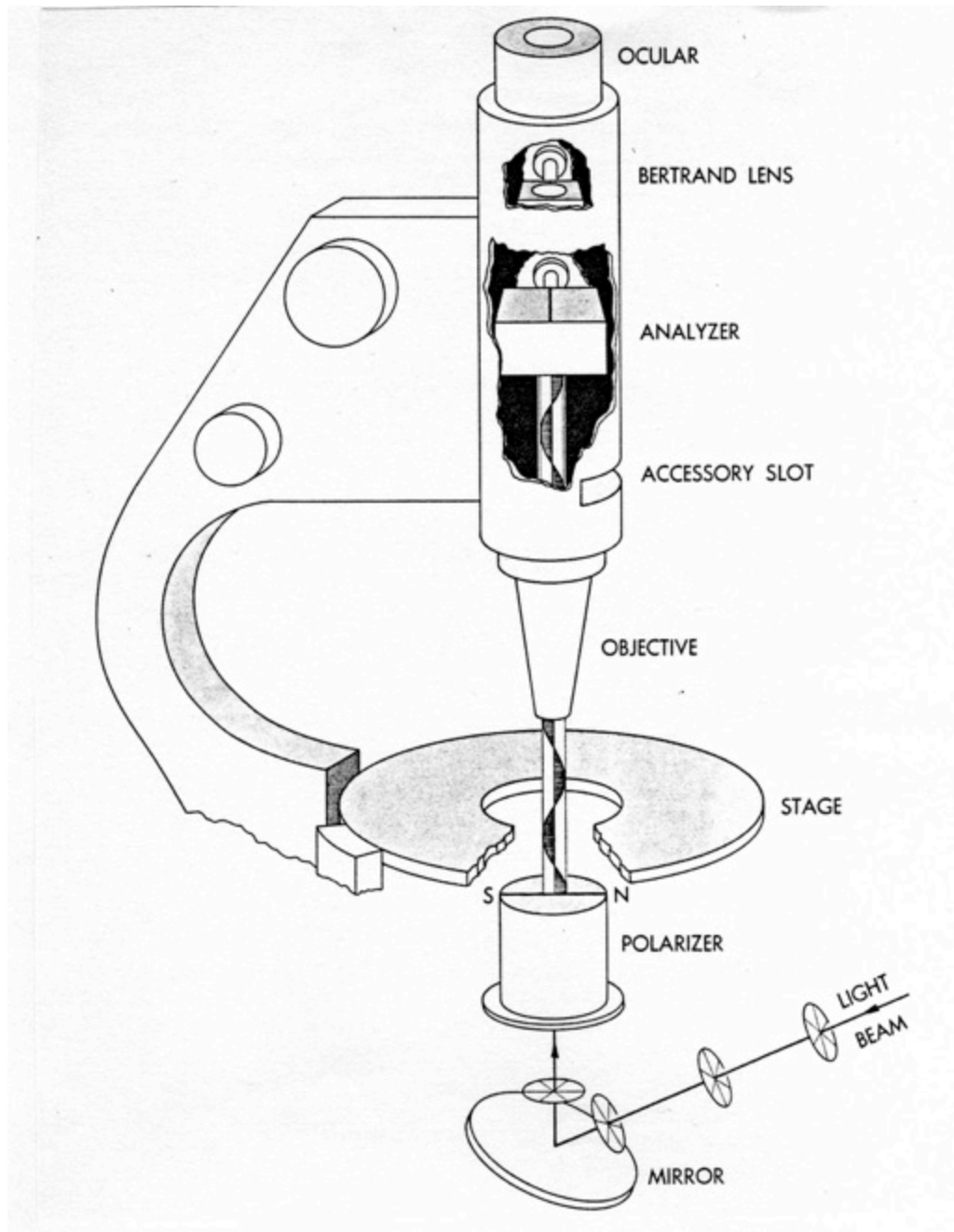


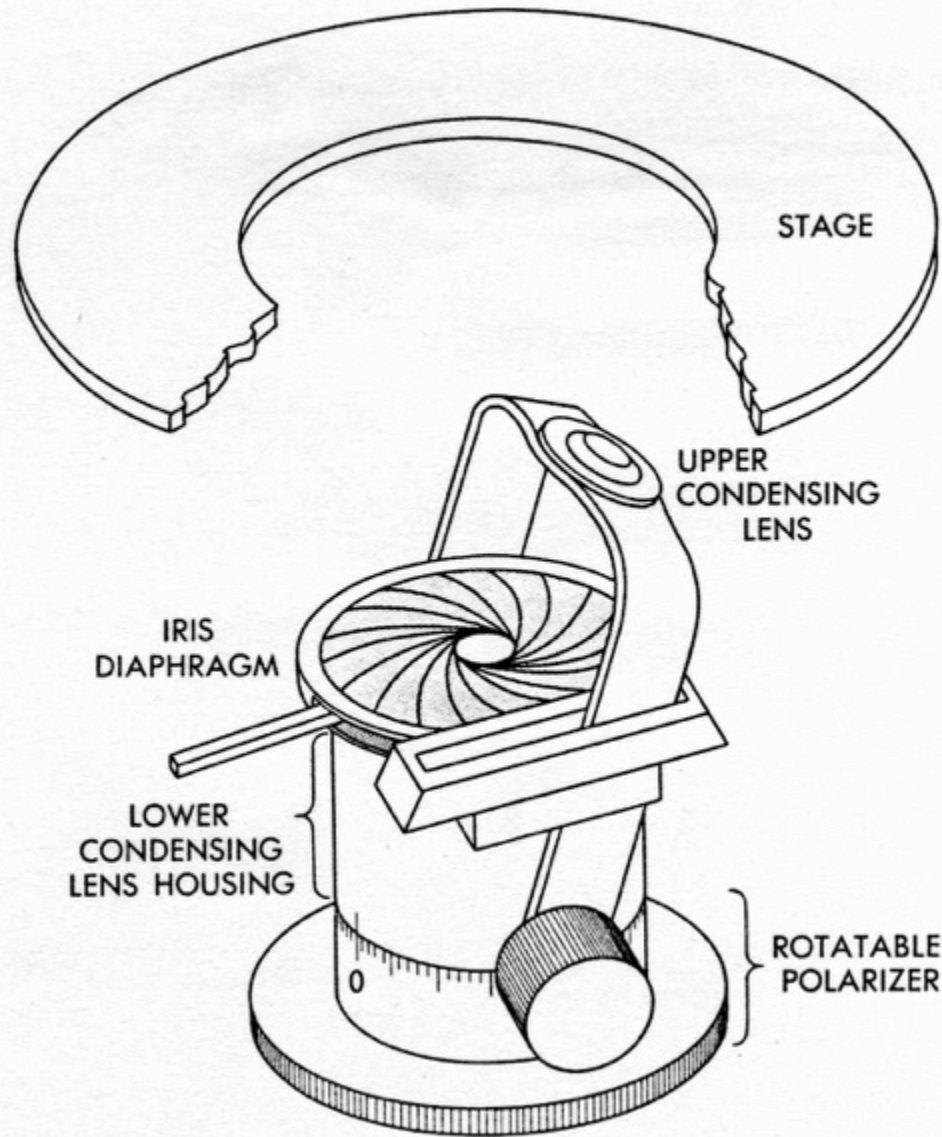
$$n = c/v$$

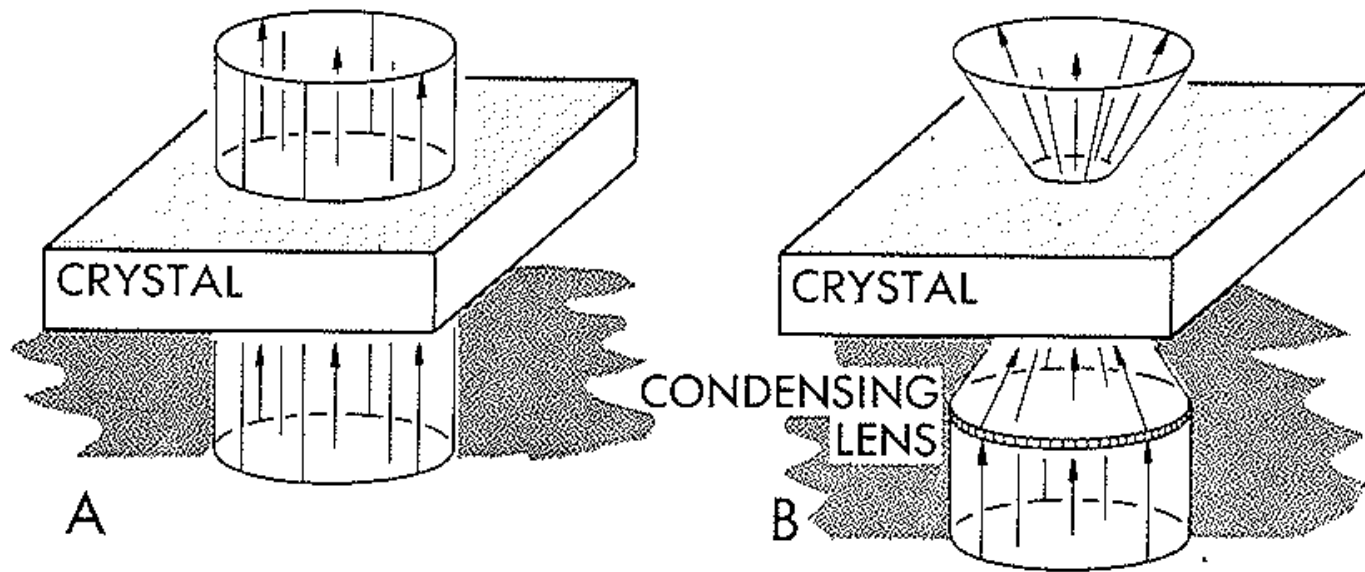
$$= c/f\lambda$$



**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).

# Isotropia e Anisotropia

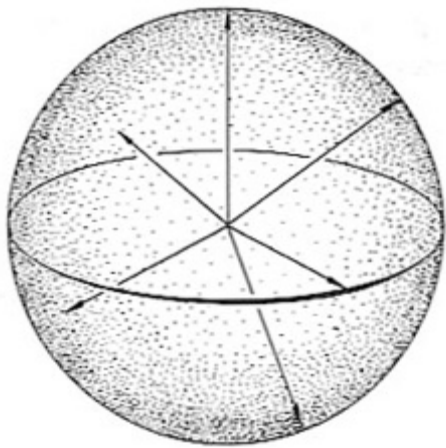
I minerali monometrici, il vetro, i liquidi e i gas hanno un valore dell'indice di rifrazione unico, indipendentemente dall'orientazione dei raggi luminosi. Tali sostanze sono dette **ISOTROPE**.

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**.



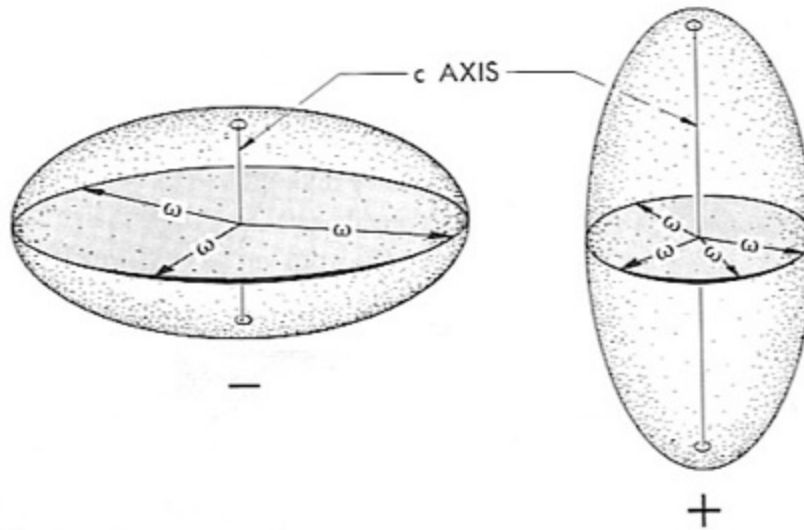
# Indicatrici Ottiche

- 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.



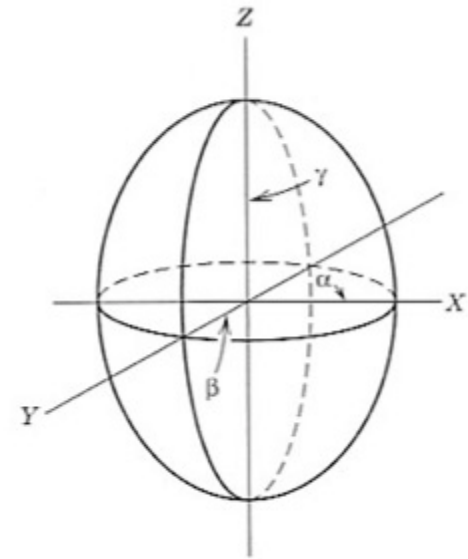
**Isotropo**

**Monometrico**



**Anisotropo - Uniassico**

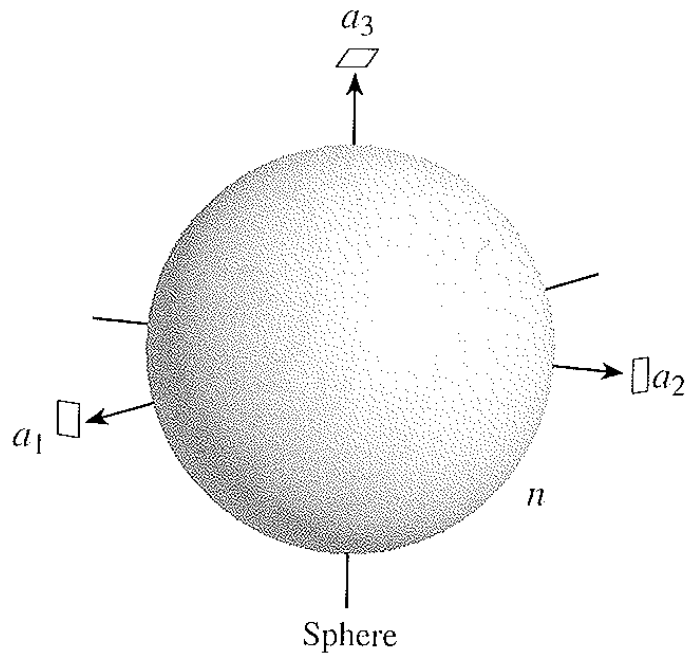
**Tetragonale**  
**Trigonale Hexagonale**



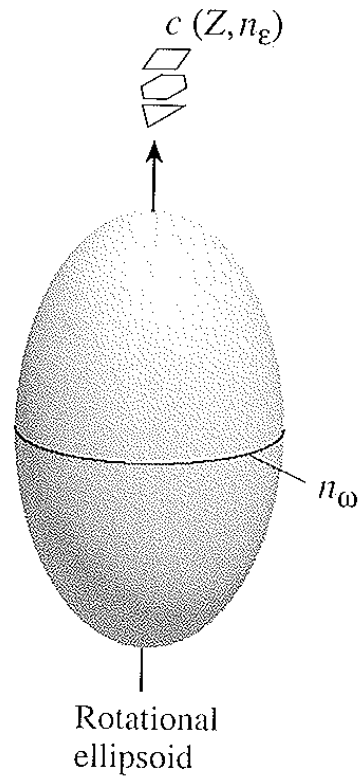
**Anisotropo - Biassico**

**Ortorombico**  
**Monoclino**  
**Triclino**

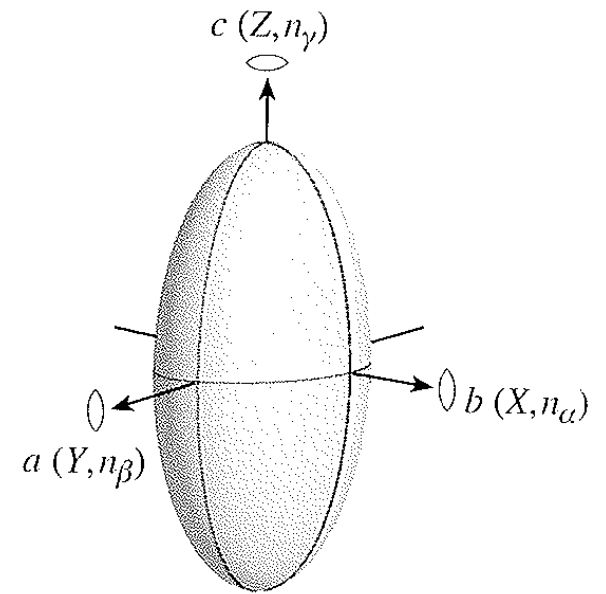
# Indicatrici Ottiche



(a)

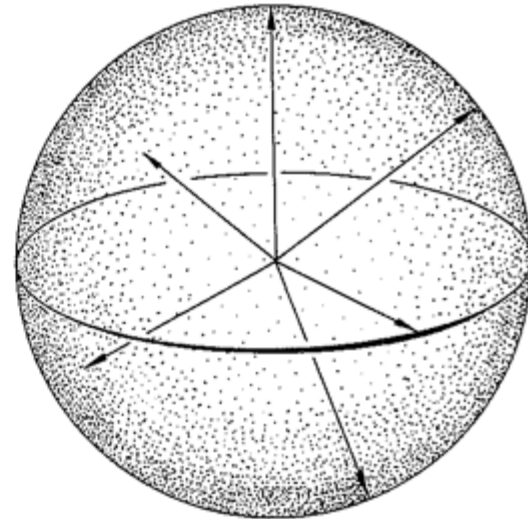


(b)



(c)

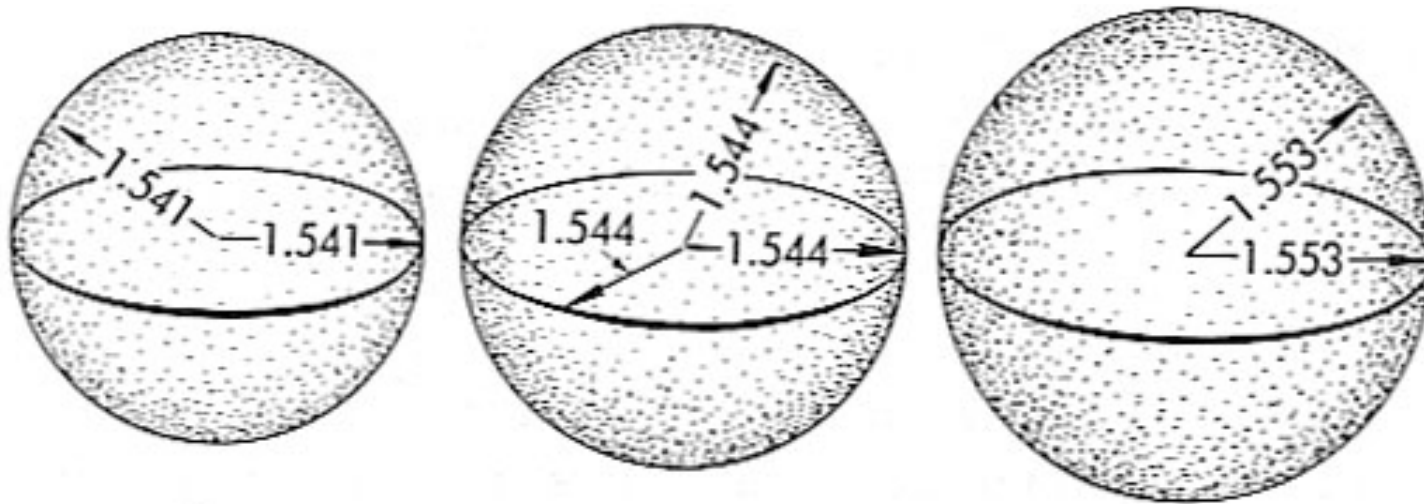
**Fig. 6-3.** Isotropic indicatrix of a crystal for sodium light. The crystal's refractive index for sodium light ( $n_D$ ) remains constant regardless of the direction in which the light is vibrating; the indicatrix is therefore a sphere.



## THE ISOTROPIC INDICATRIX

# Indicatrice Isotropa

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



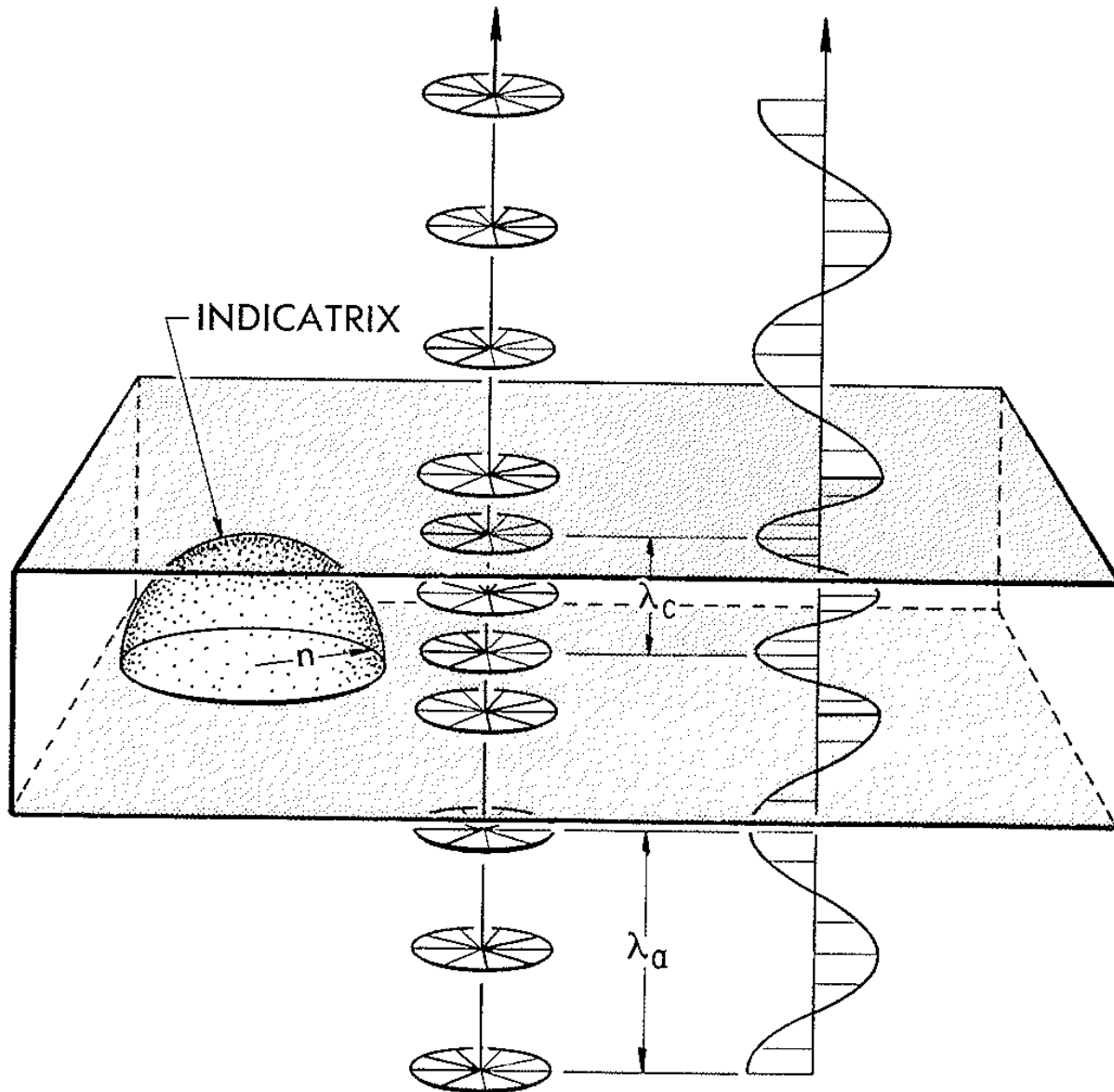
$\lambda_c$  6563Å Red

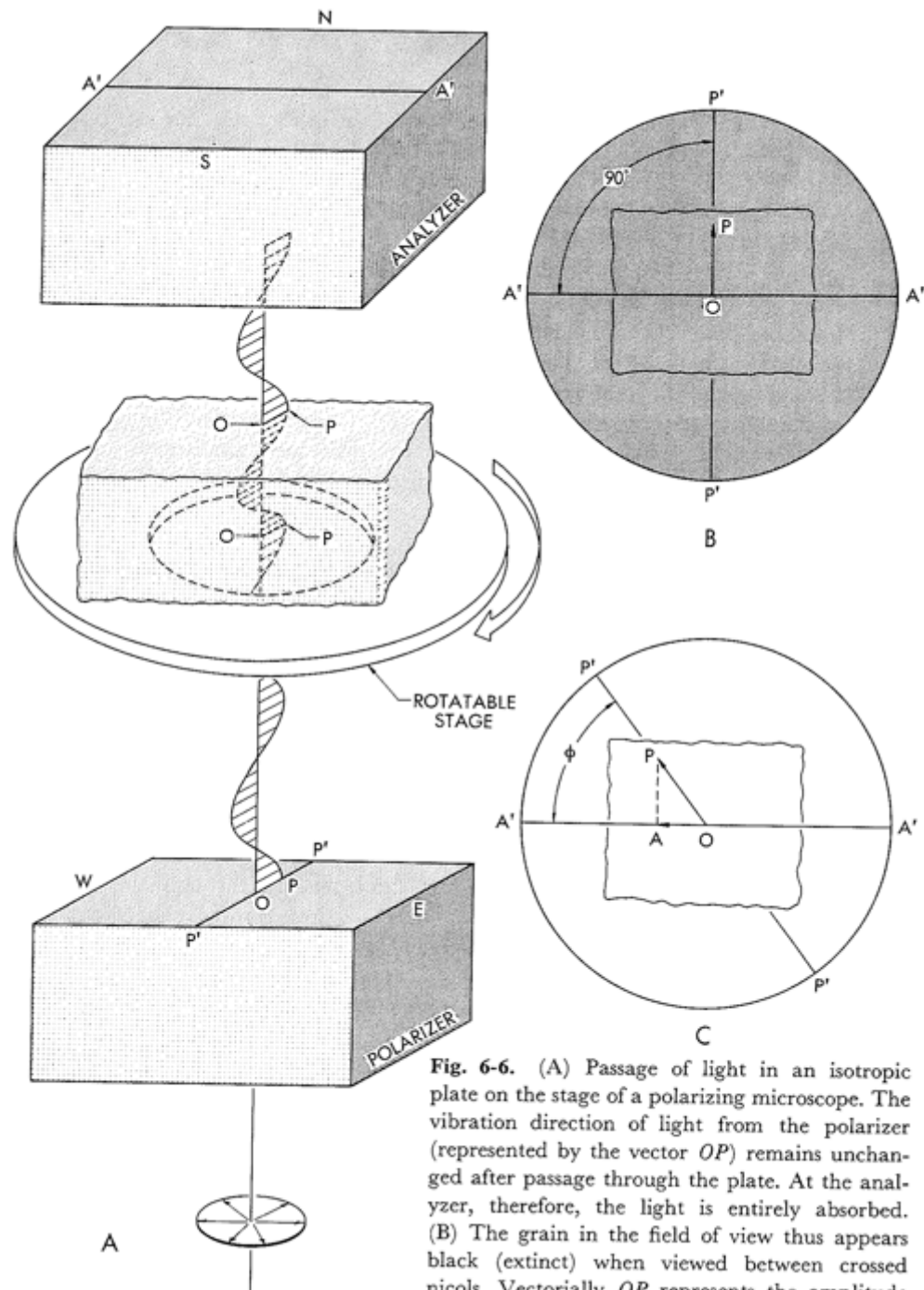
$\lambda_D$  5893Å Yellow

$\lambda_F$  4861Å Blue

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

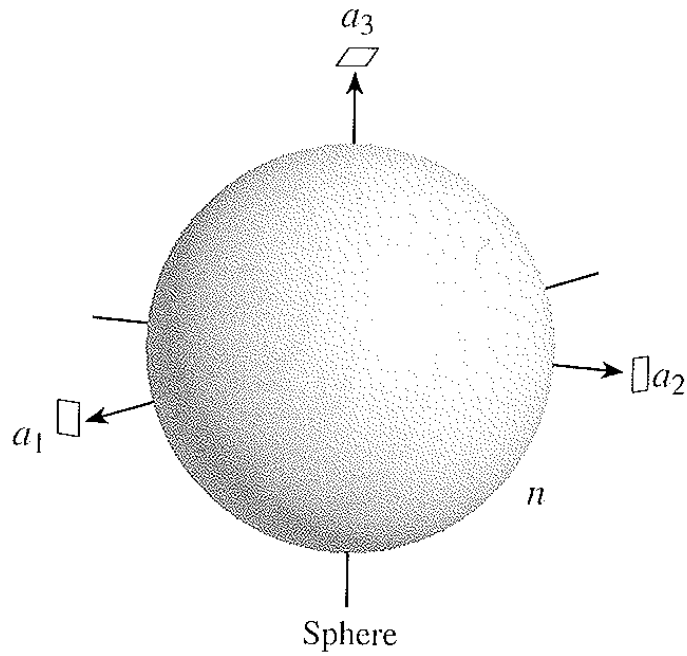
Le tre sfere rappresentano i valori di ***n*** per diverse lunghezze d'onda della luce nello stesso minerale.



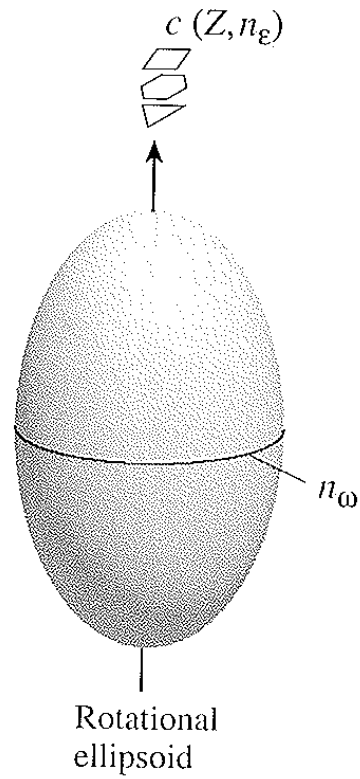


**Fig. 6-6.** (A) Passage of light in an isotropic plate on the stage of a polarizing microscope. The vibration direction of light from the polarizer (represented by the vector  $OP$ ) remains unchanged after passage through the plate. At the analyzer, therefore, the light is entirely absorbed. (B) The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

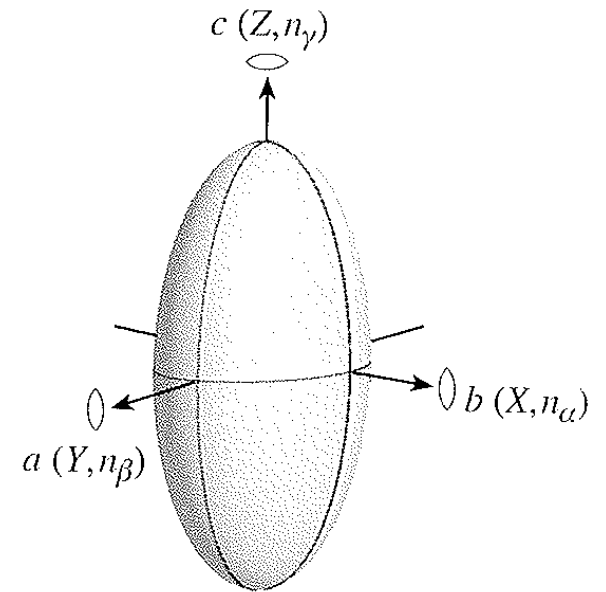
# Indicatrici Ottiche



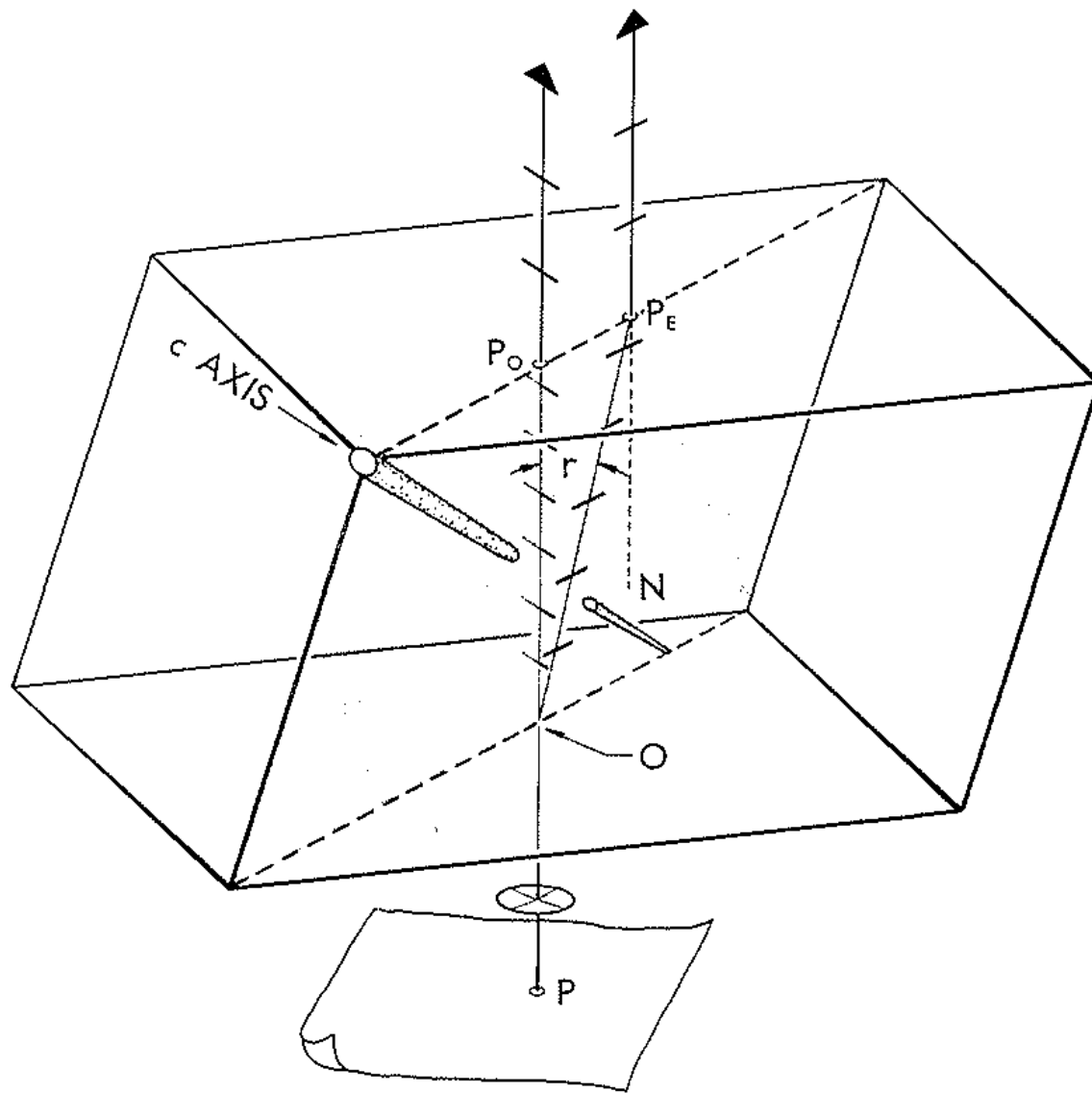
(a)



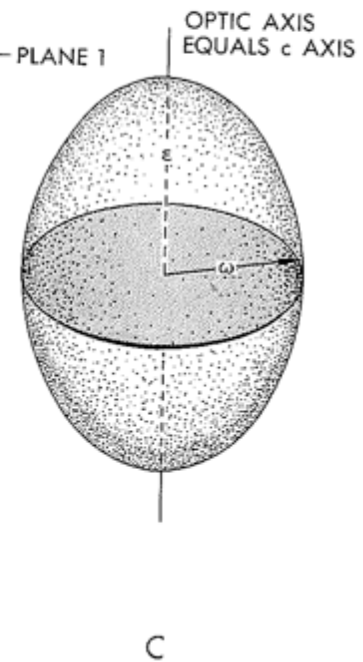
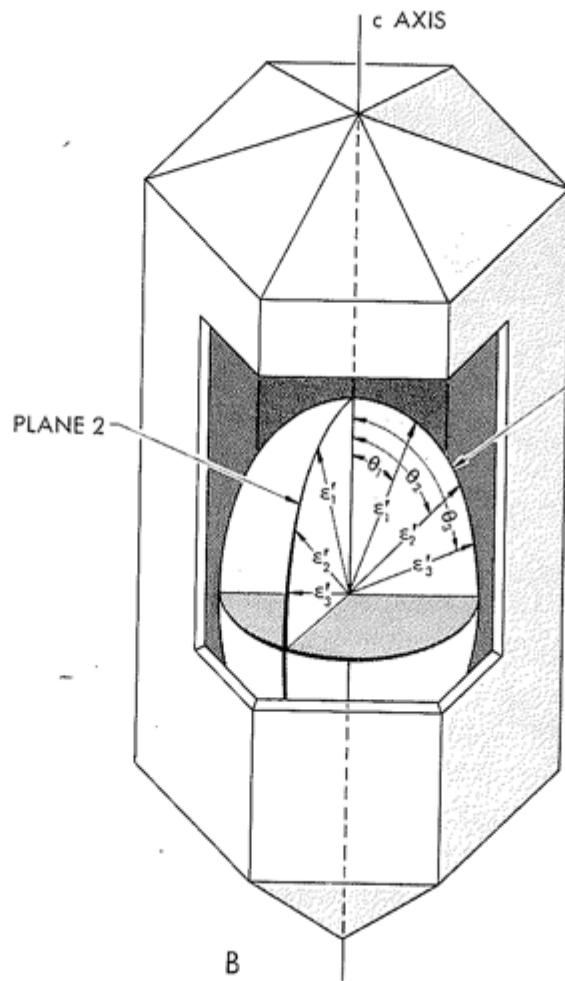
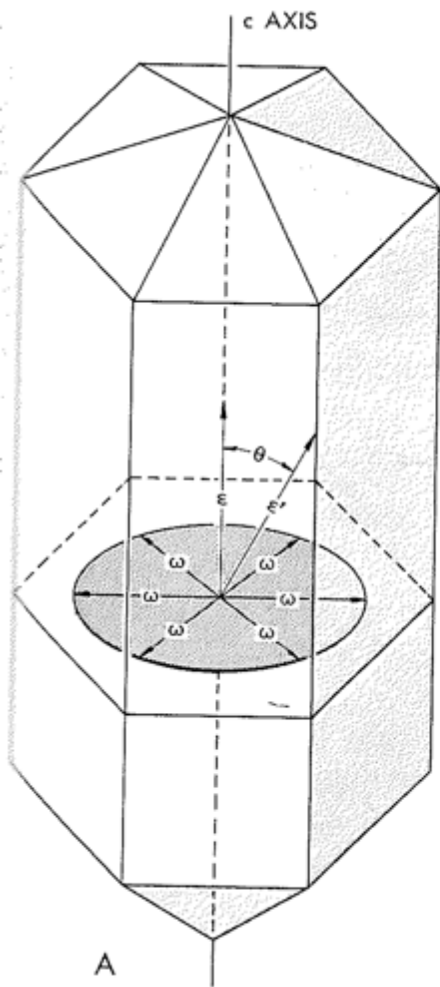
(b)



(c)

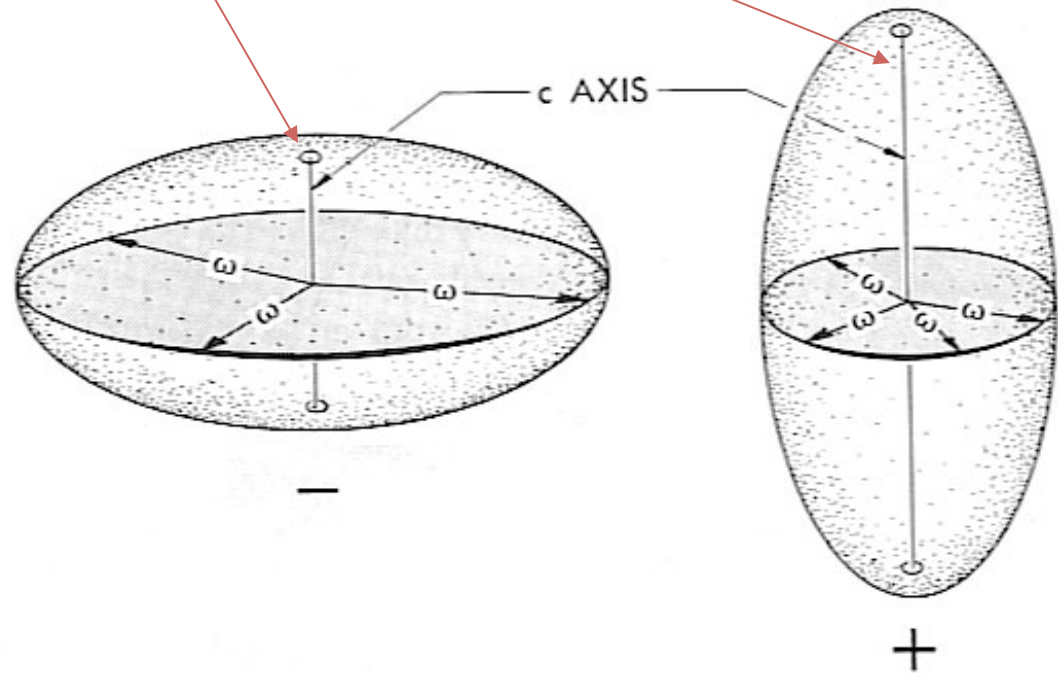
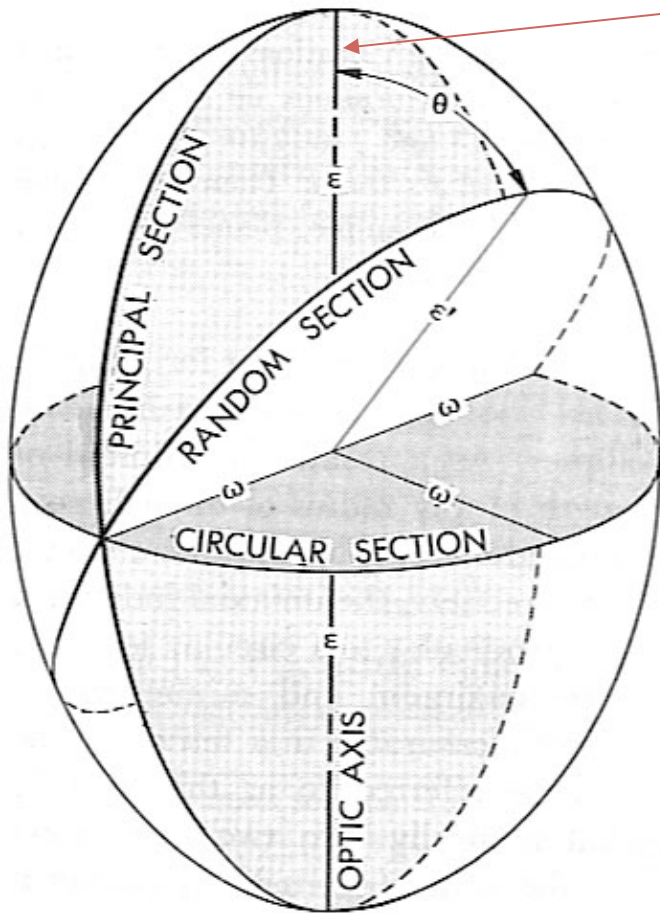


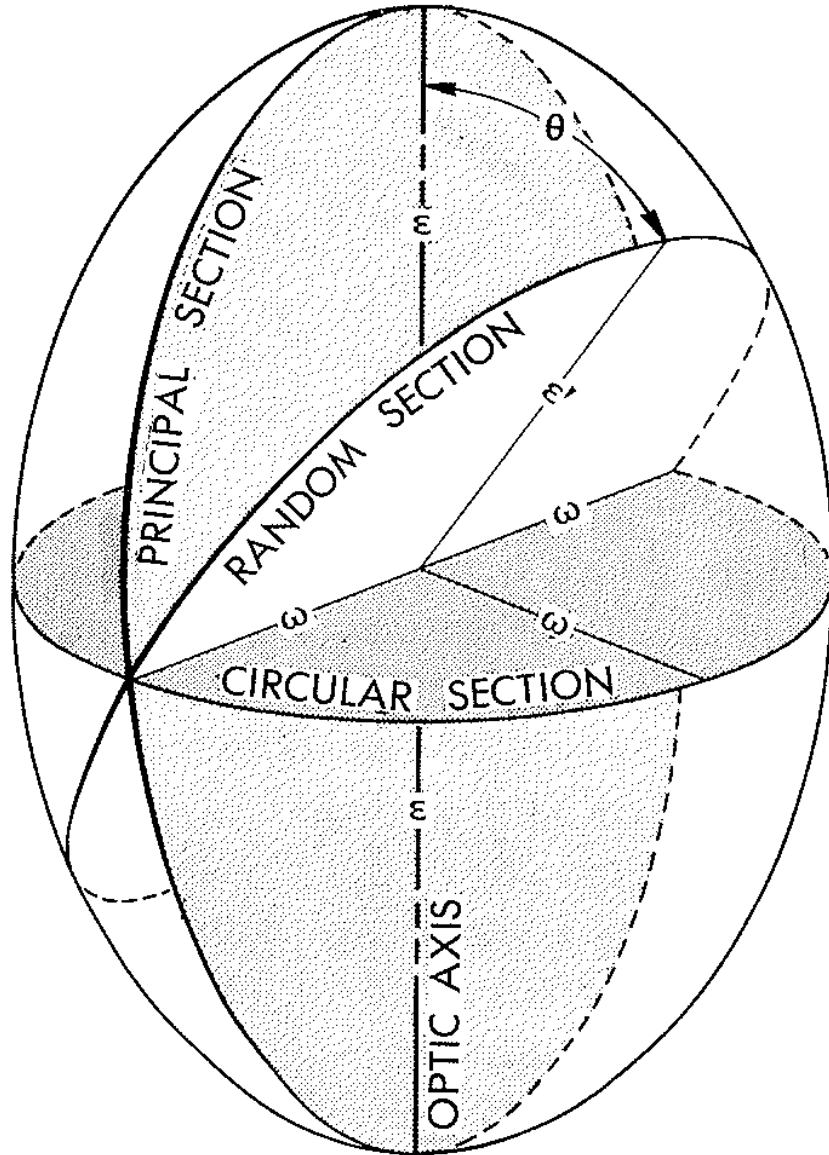


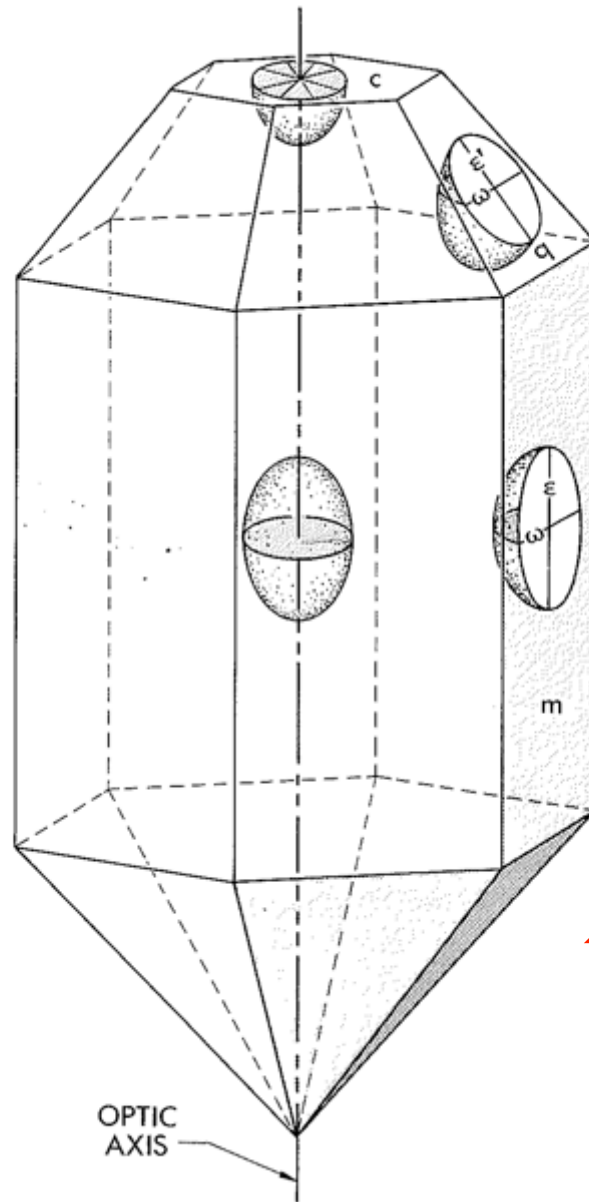


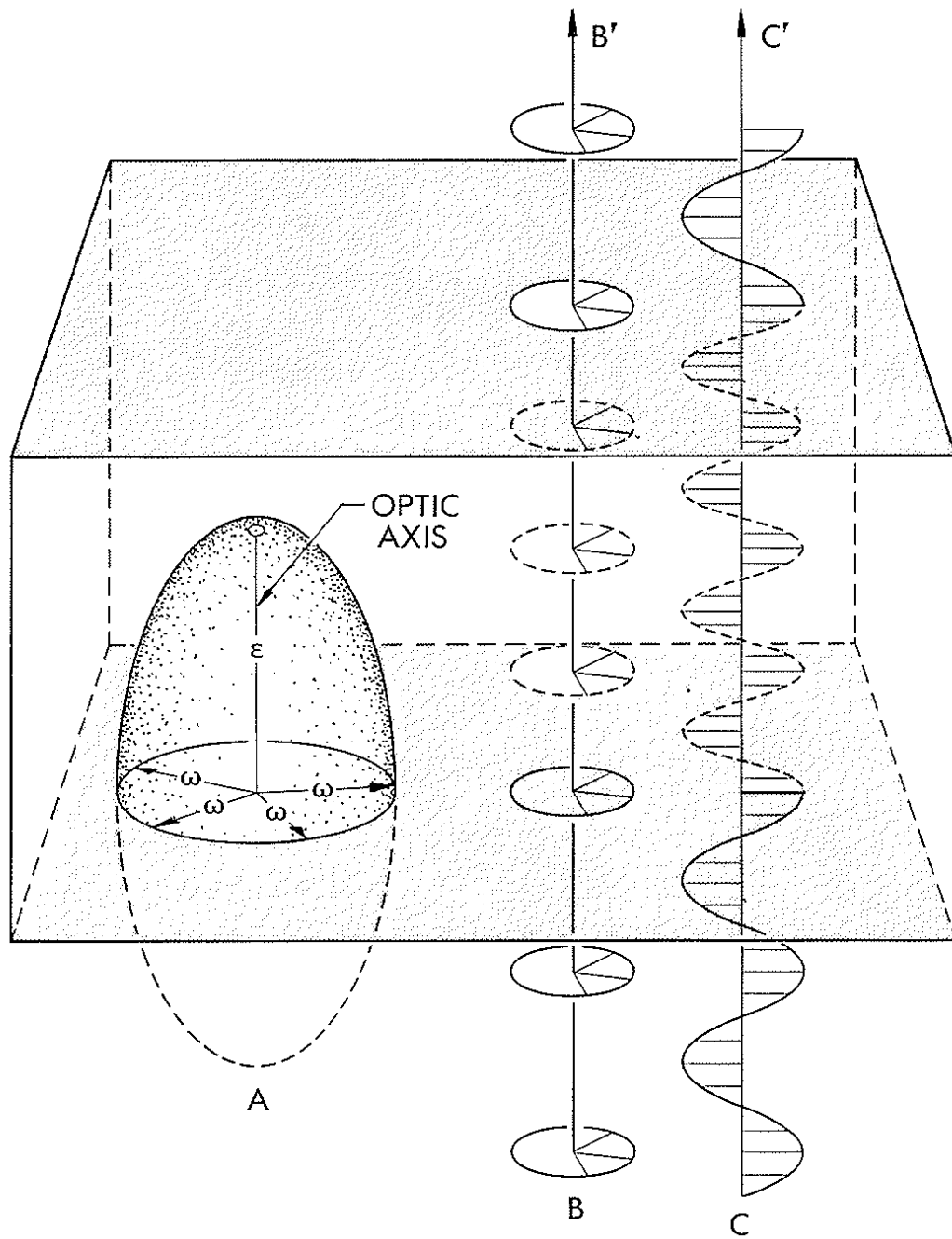
# Uniaxial Indicatrix

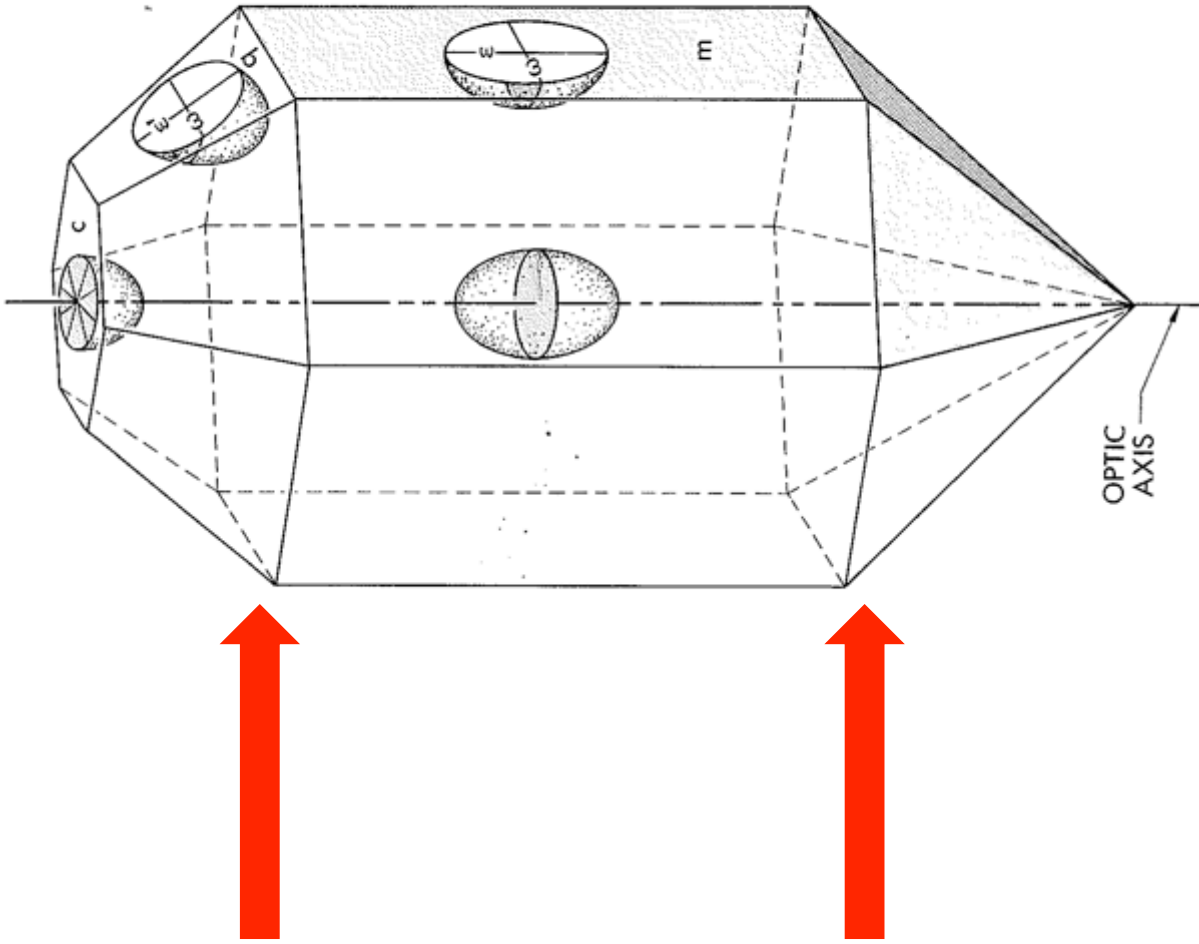
Asse Ottico = l'asse C  
nei cristalli trigonali,  
tetragonali e esagonali

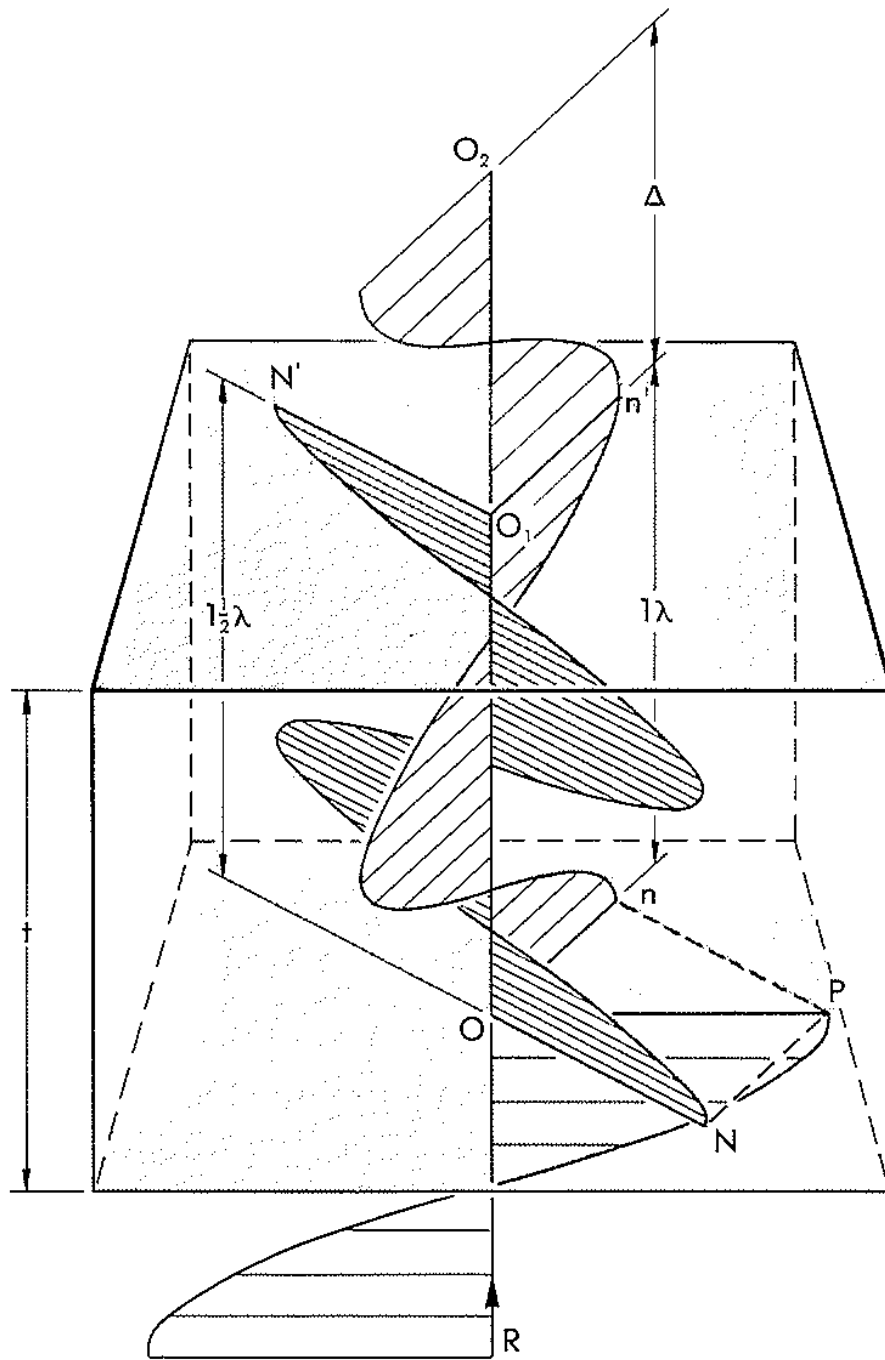








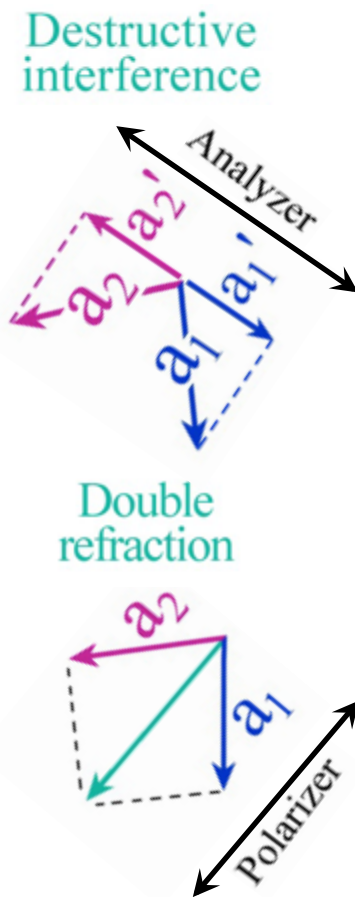
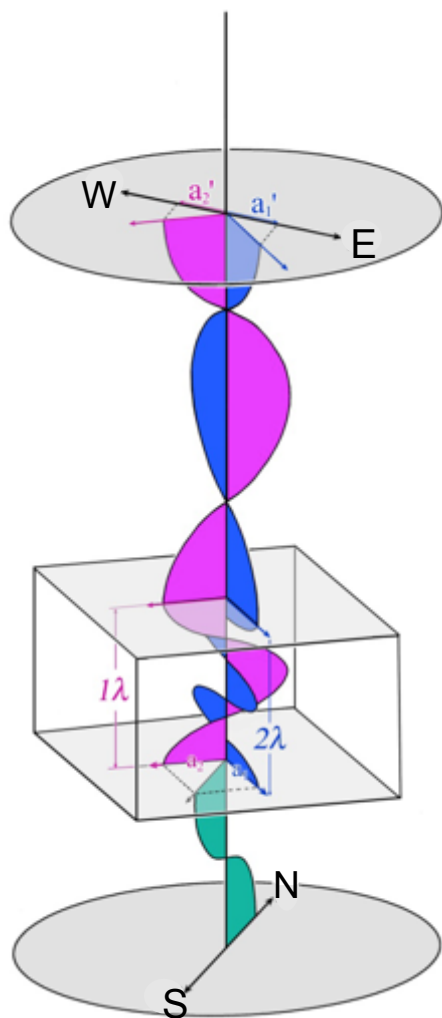




# COLORI D'INTERFERENZA - MINERALI BIRIFRANGENTI

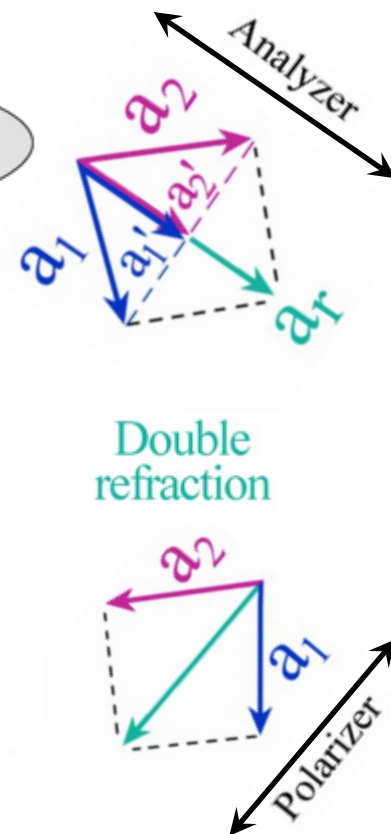
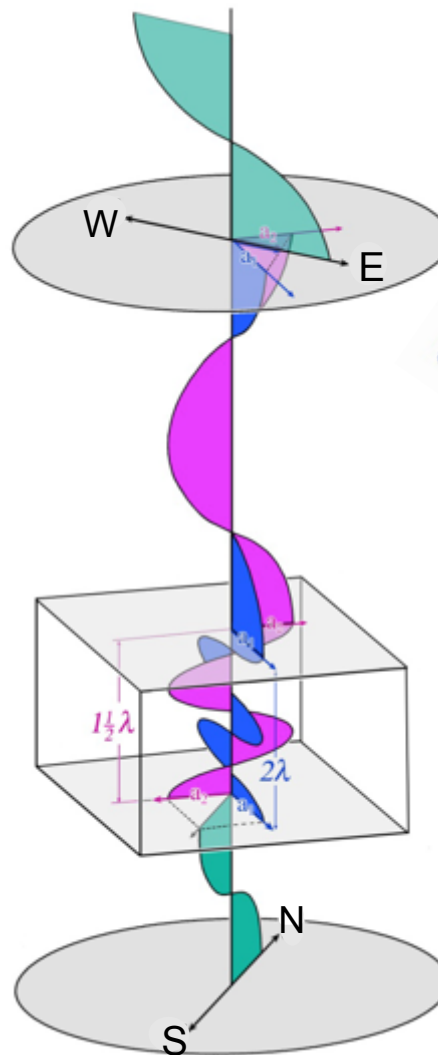
Passaggio della luce (per semplicità solo monocromatica) attraverso un minerale anisotropo orientato a 45° rispetto alla direzione dei polarizzatori

**A**



Onda viola veloce associata all'indice n piccolo  
Onda blu lenta associata all'indice n grande

Constructive interference



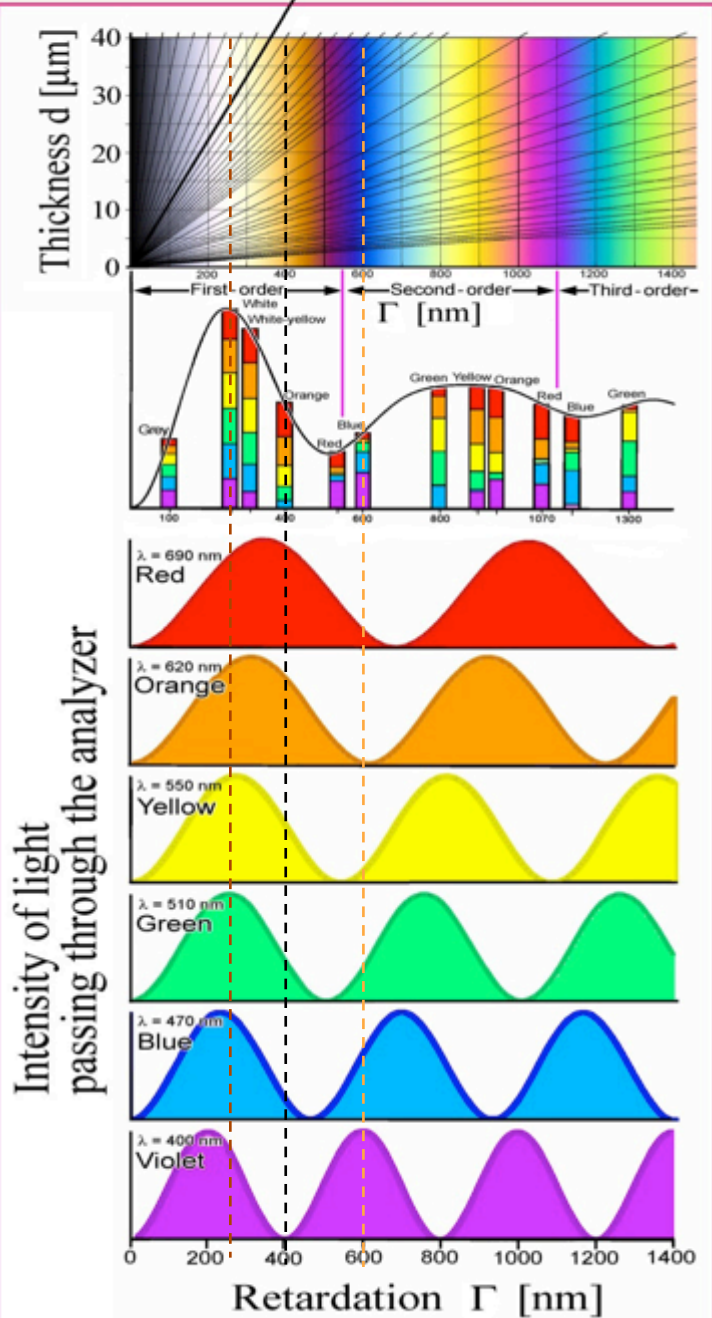
**A: interferenza distruttiva** – il ritardo tra le 2 onde accumulato nel cristallo è pari a  $\lambda$  (o un n° pari di  $\lambda$ )

**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,
- 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.

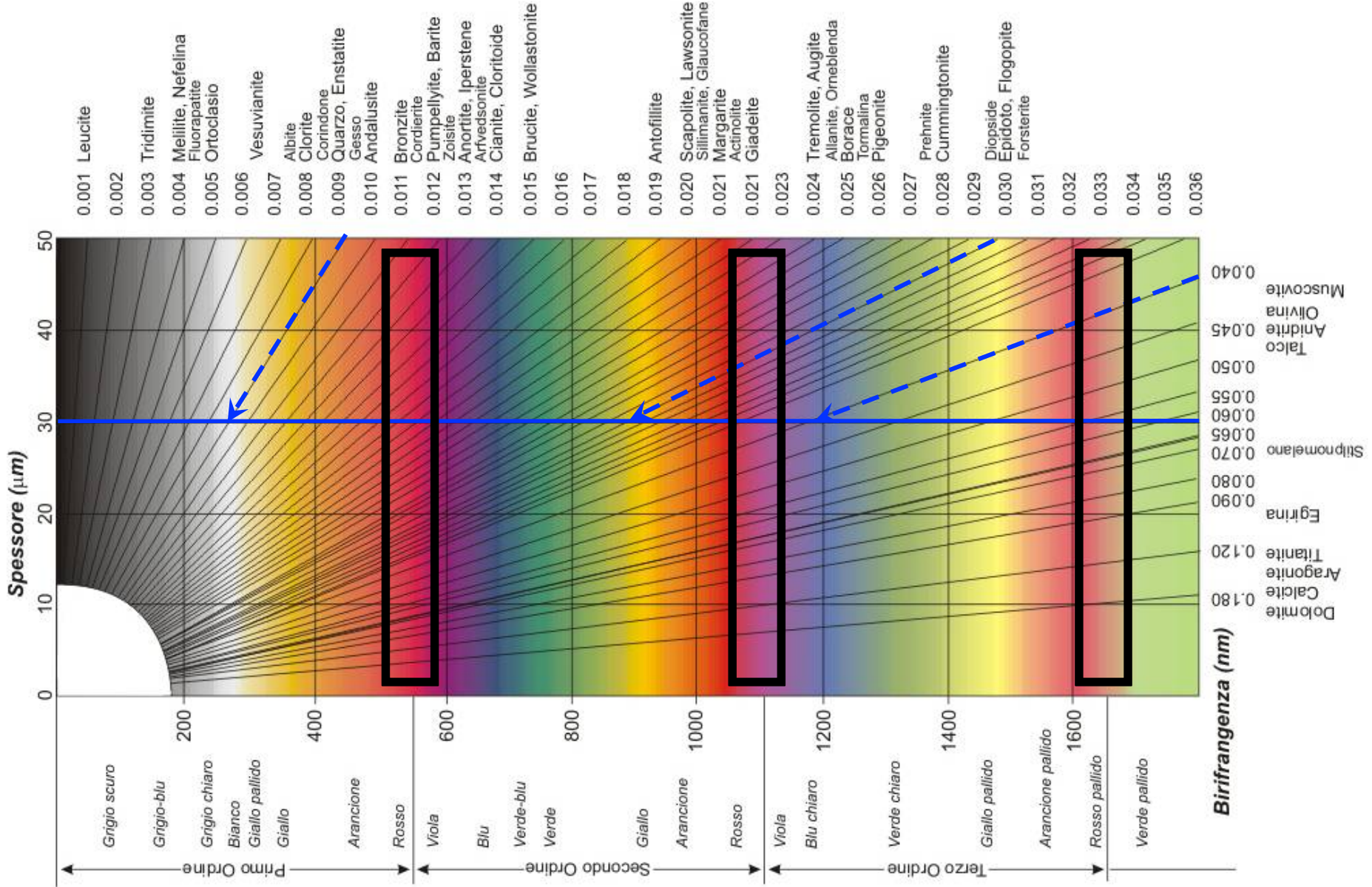
Uno specifico colore d'interferenza, caratterizzato da una precisa composizione spettrale, compare una volta sola nella carta dei colori.

*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*

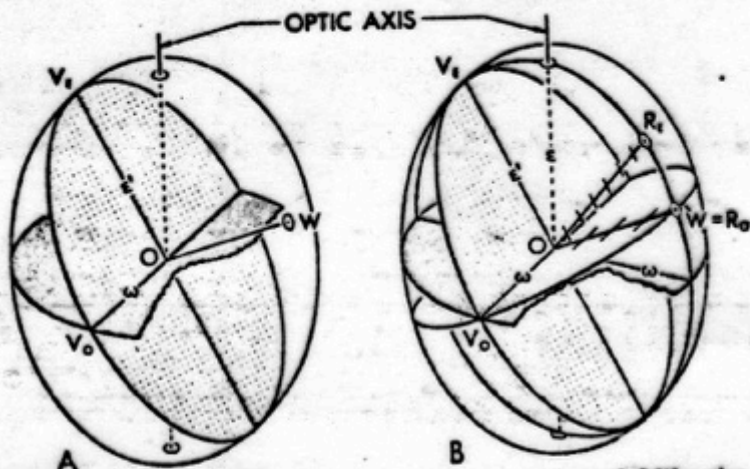
luce bianca

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

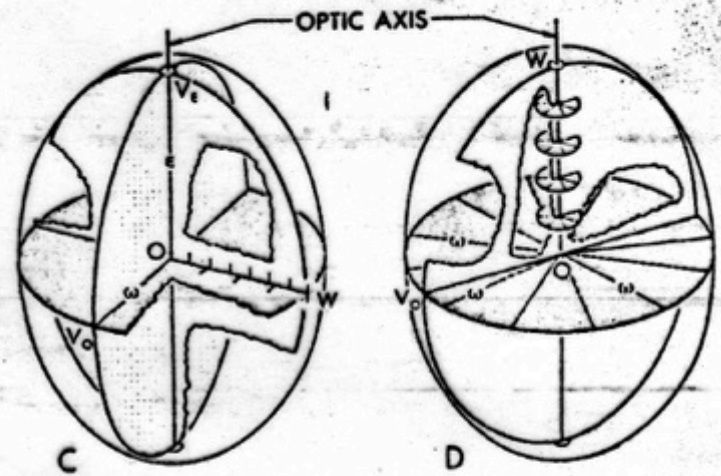
$$(n_\gamma - n_\alpha) = \text{birifrangenza (linee)}$$



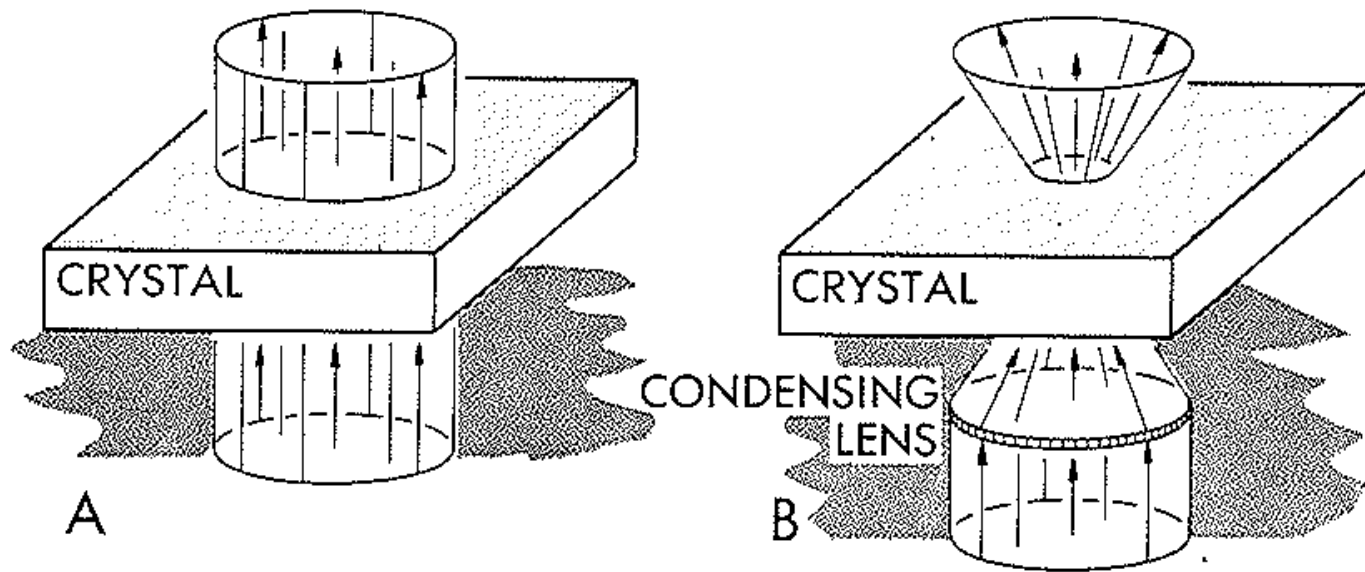
RITARDO distinto in vari ordini di colori (in nm dove  $1\text{nm} = 10^{-3}\mu = 10\text{\AA} = 10^{-7}\text{cm}$ )



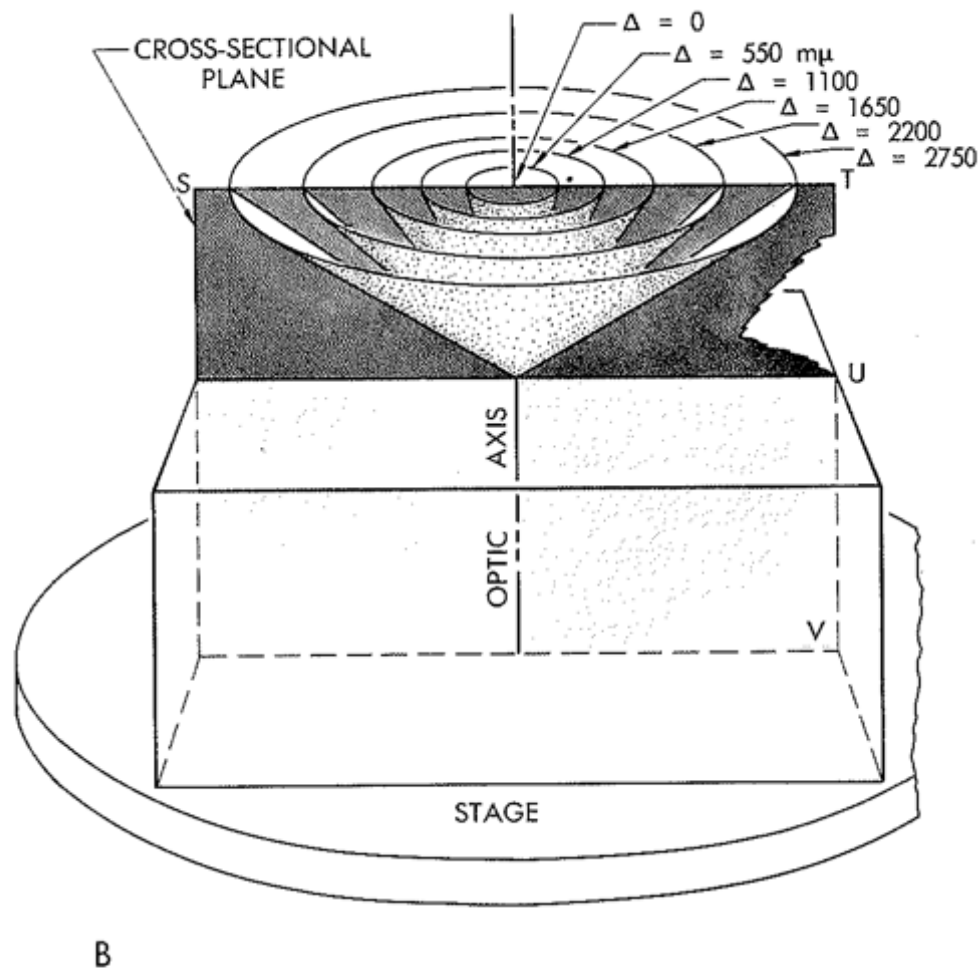
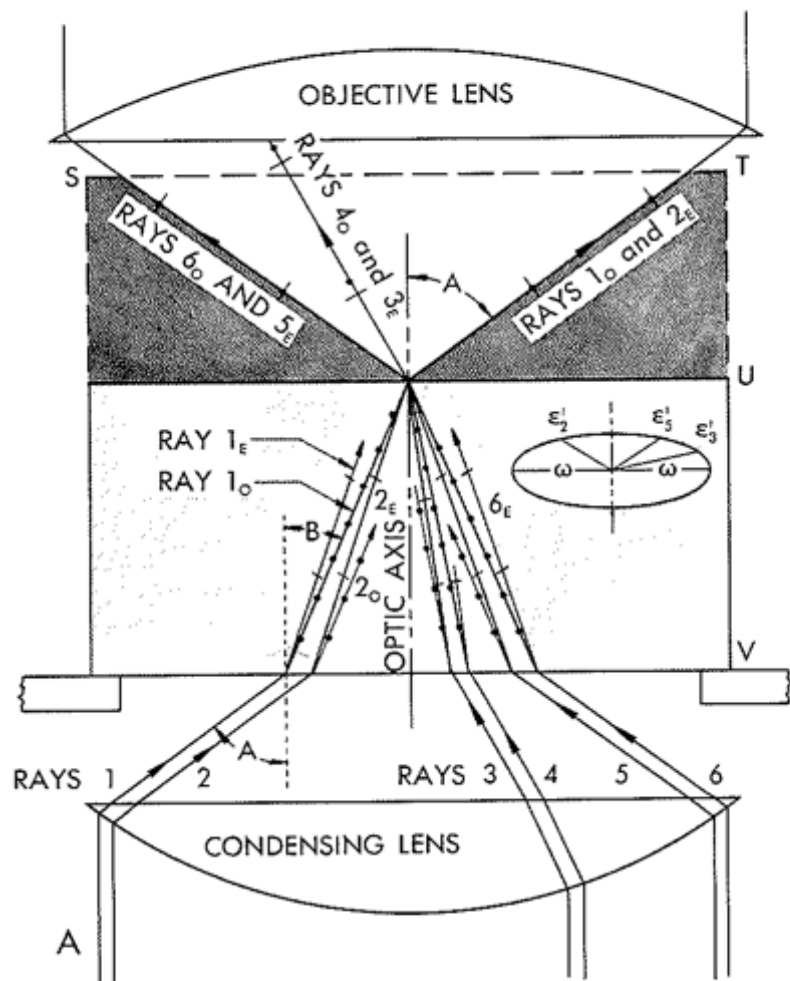
**Fig. 6-13A-B.** (A) Relation of a random wave normal  $OW$  to the only two vibration directions,  $OV_O$  and  $OV_E$ , that are associate with it. The stippled plane perpendicular to  $OW$  intersects the indicatrix in an ellipse for which  $OV_O$  and  $OV_E$  are semi-axes. (B) Location of  $OR_E$ , the only ray path associate with  $OW$  and  $OV_E$ . All three lie in the same plane (shaded gray). Similarly, ray path  $OR_O$ , the only path associate with  $OW$  and  $OV_O$ , lies in the same plane (unshaded) with them;  $OR_O$  coincides with  $OW$  in this instance. In both (A) and (B) the circular section is shaded dark gray.



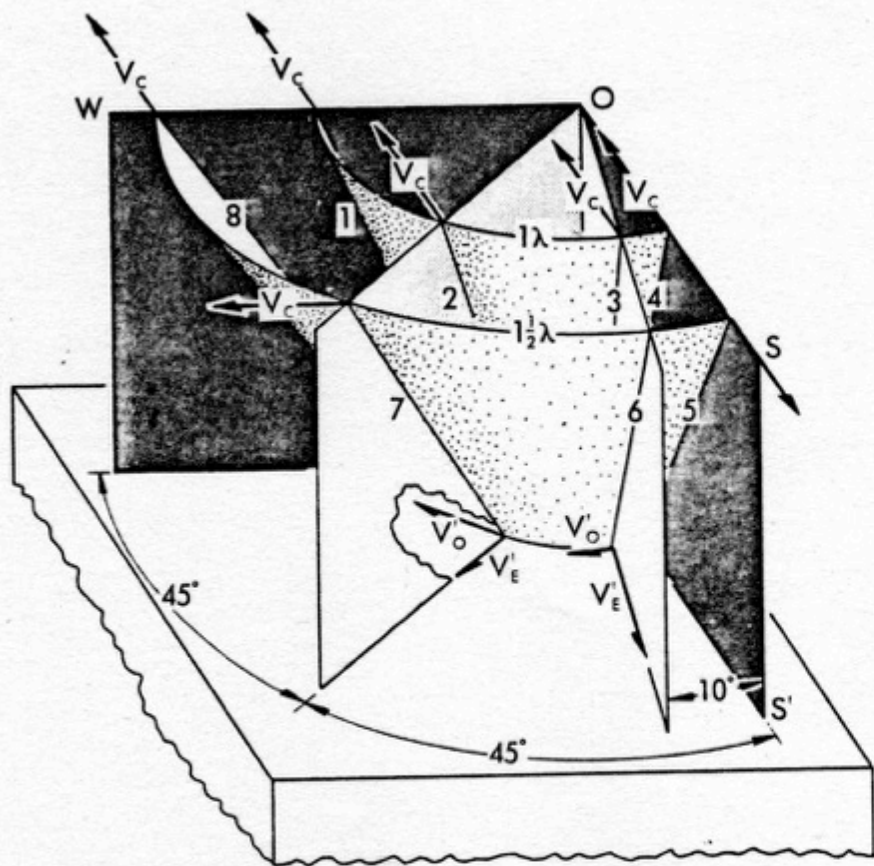
**Fig. 6-13C-D.** (C) Relation of vibration directions ( $OV_O$  and  $OV_E$ ) and ray paths (these coincide with  $OW$ ) to  $OW$ , a wave normal perpendicular to the optic axis. Note coincidence of  $O$ - and  $E$ -ray paths. (D) Relation of vibration directions (which are all possible radii of the heavily shaded circular section) and ray path (coincident with  $OW$ ) to a wave normal,  $OW$ , parallel to the optic axis. In both (C) and (D) the circular section is shaded dark gray.



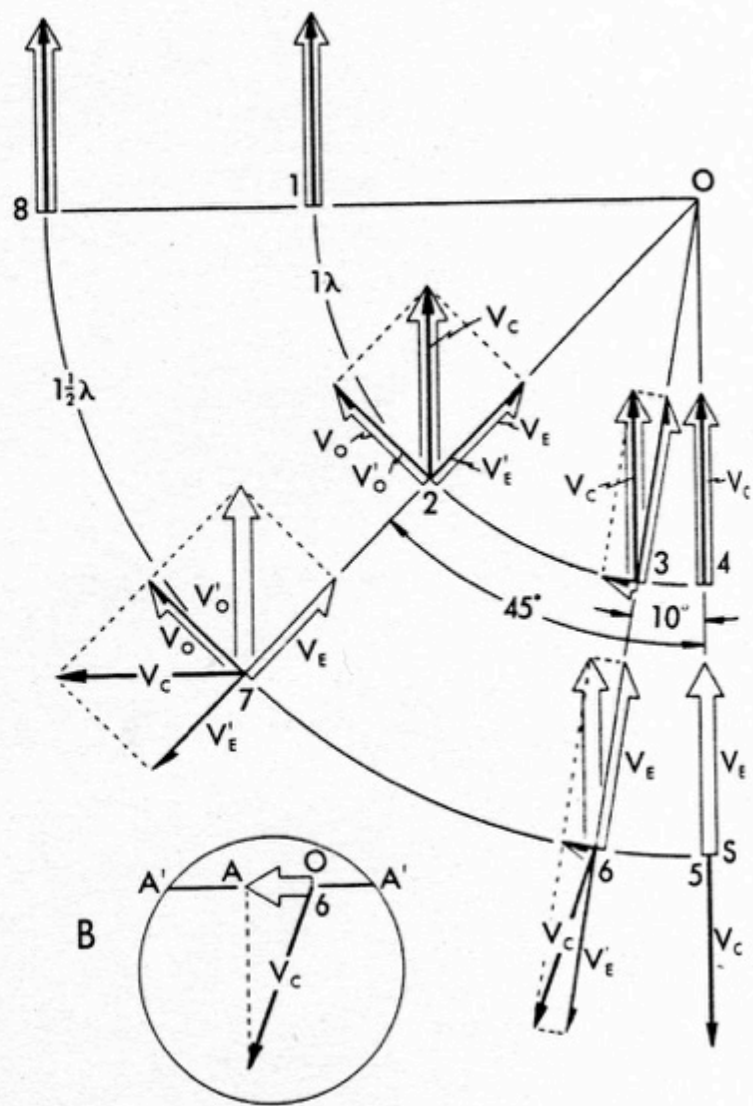
**Fig. 7-10.** Comparison of the ray paths for orthoscopic illumination (A) and conoscopic illumination (B). For the actual situation the rays shown in (A) would be slightly convergent. They become increasingly parallel, however, as the apertures are decreased (for example, by closing down the iris diaphragm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



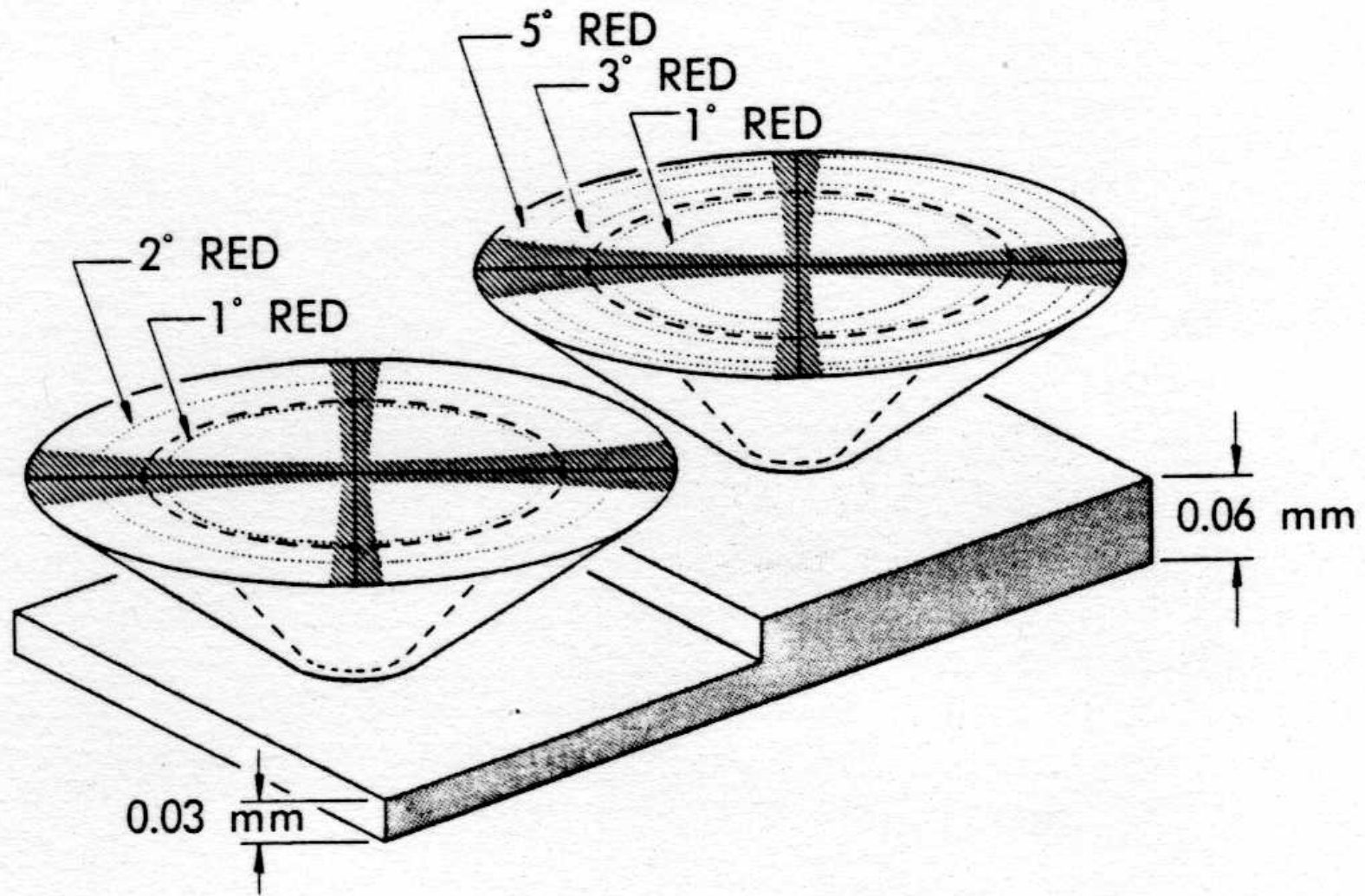
**Fig. 7-13.** (A) Cross-sectional view of a conoscopically illuminated uniaxial crystal whose optic axis is perpendicular to stage. (B) Cones of equal retardation for same in perspective view. *STUV* is the cross-sectional plane drawn in (A). Crystal thickness is highly exaggerated.



A

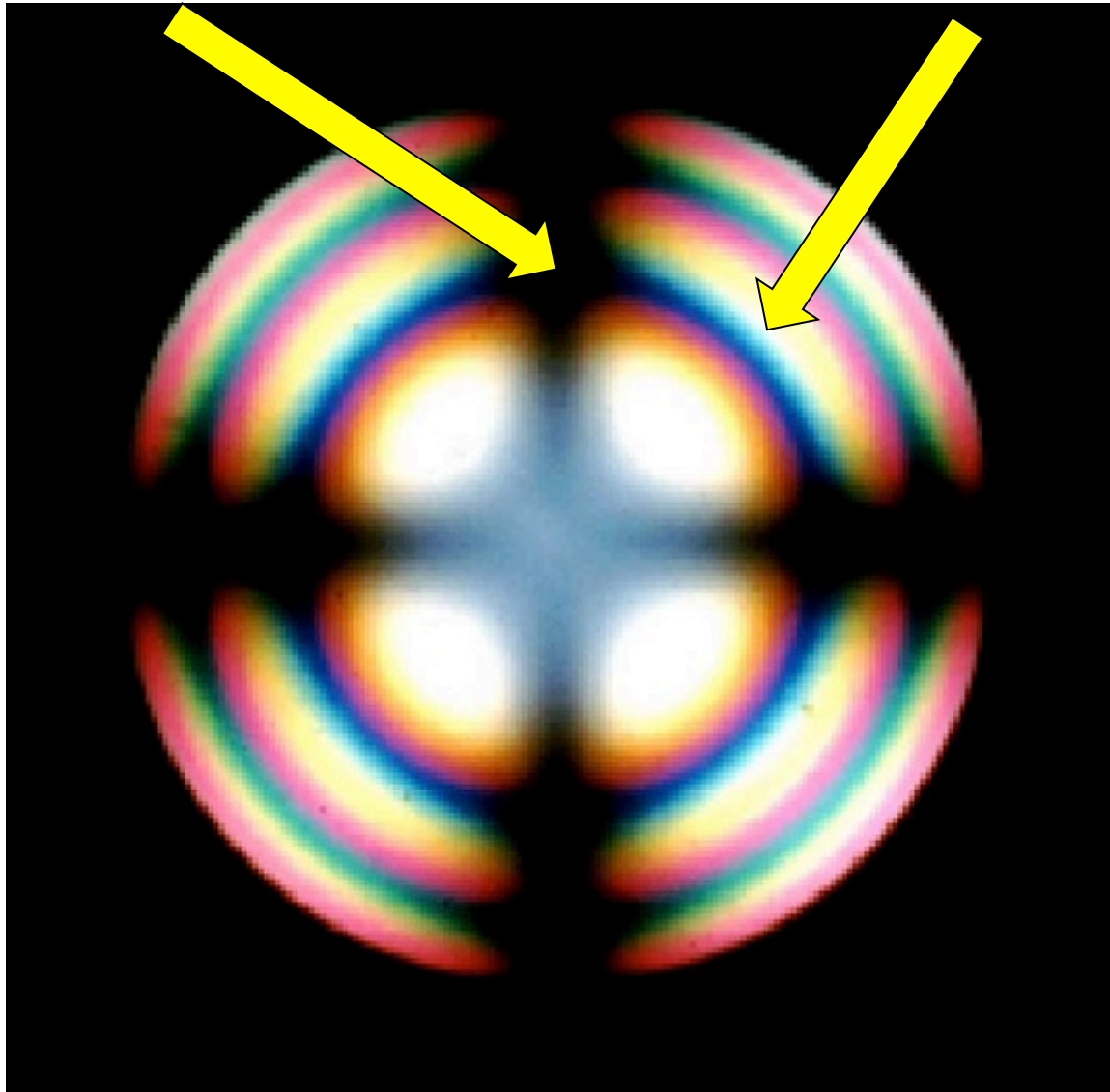


B



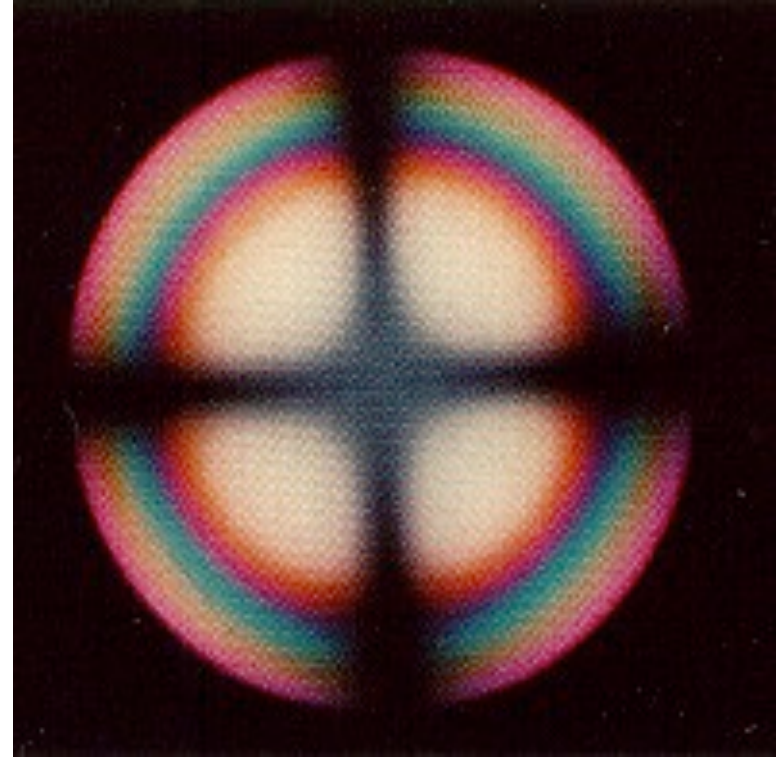
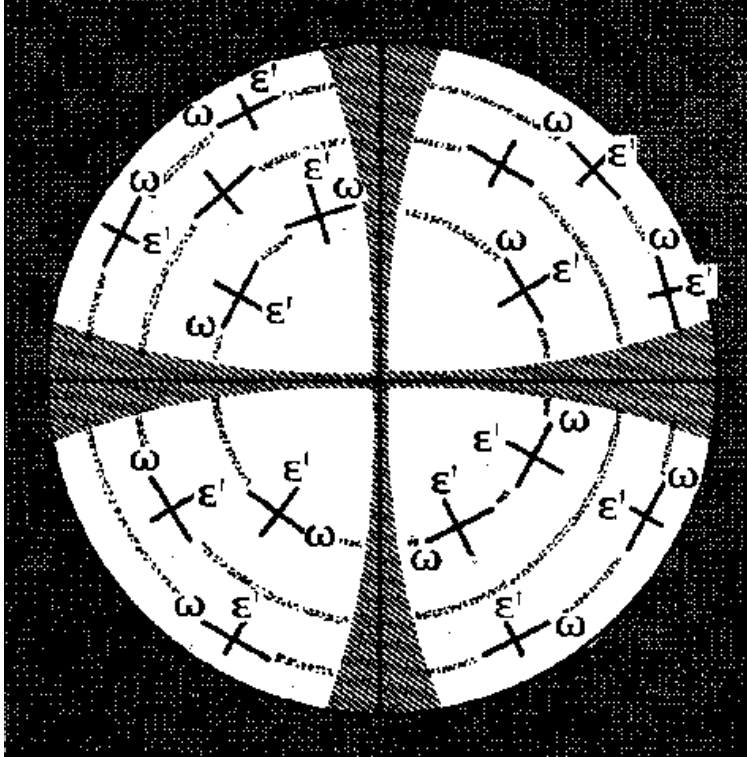
**ISOGIRE**

**ISOCROMATICHE**



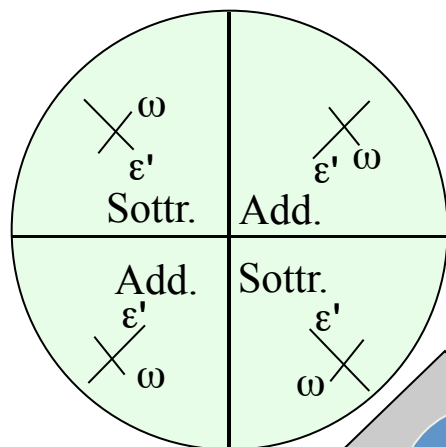
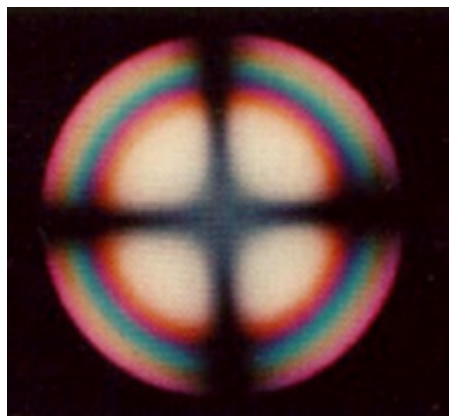


**Rispetto alle isocromatiche**  
 **$\varepsilon$  è sempre radiale e**  
 **$\omega$  è sempre tangenziale**

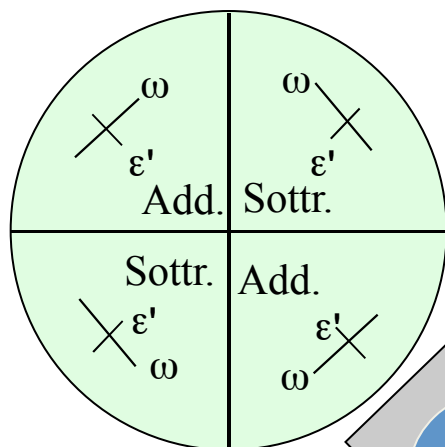
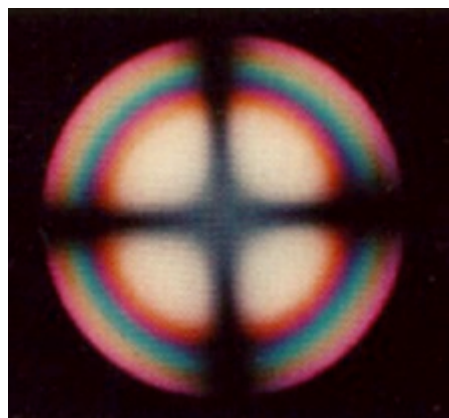
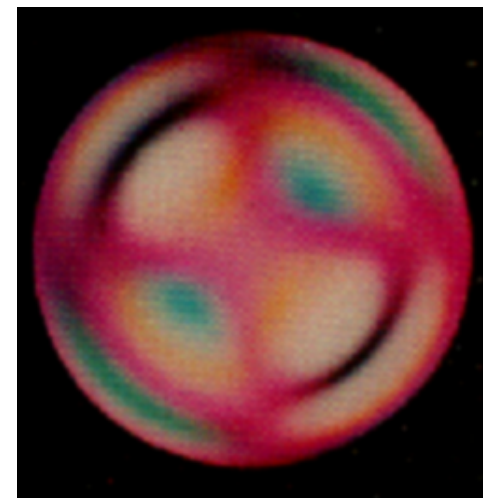


**per  $\varepsilon > \omega$  il cristallo è positivo (+)**  
**per  $\varepsilon < \omega$  il cristallo è negativo (-)**

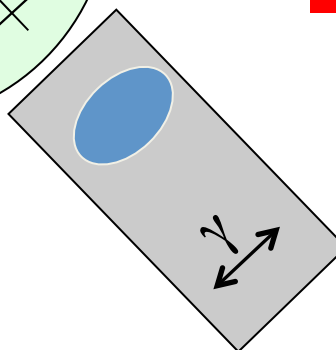
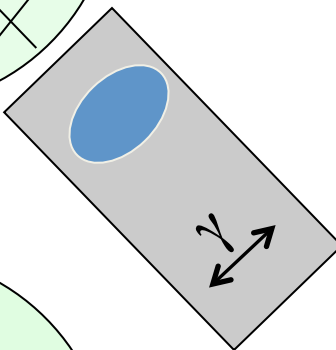
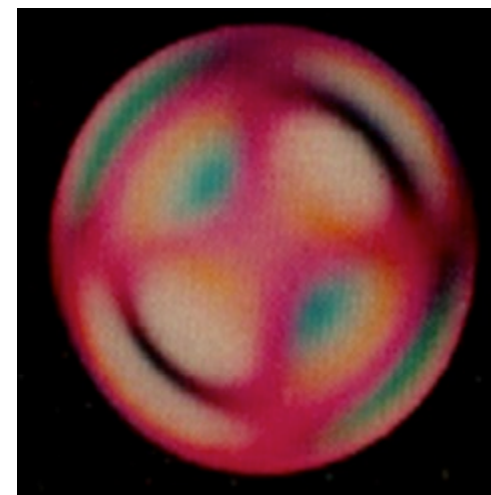
# CRISTALLO UNIASSICO : SEGNO OTTICO



+

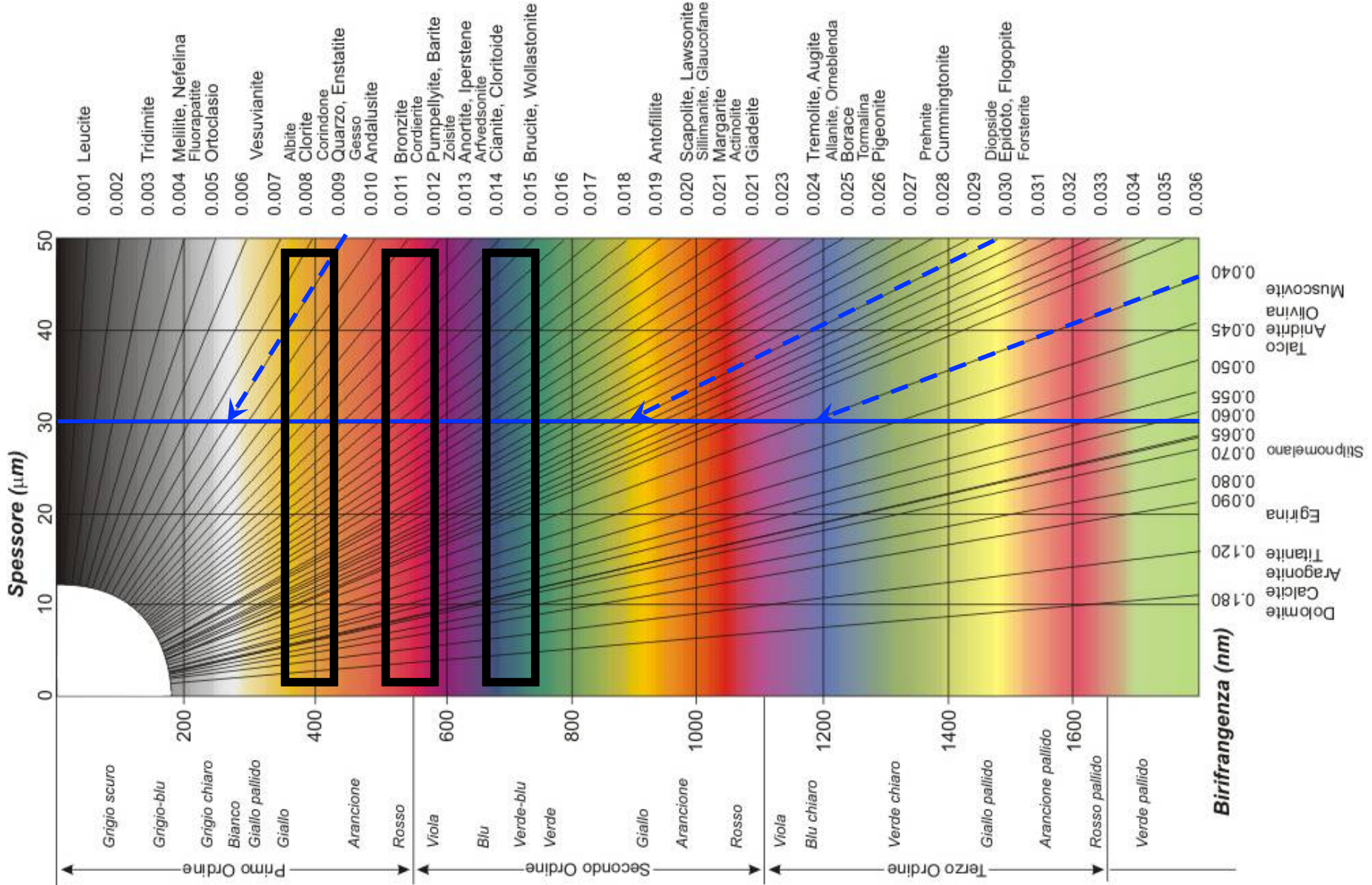


-

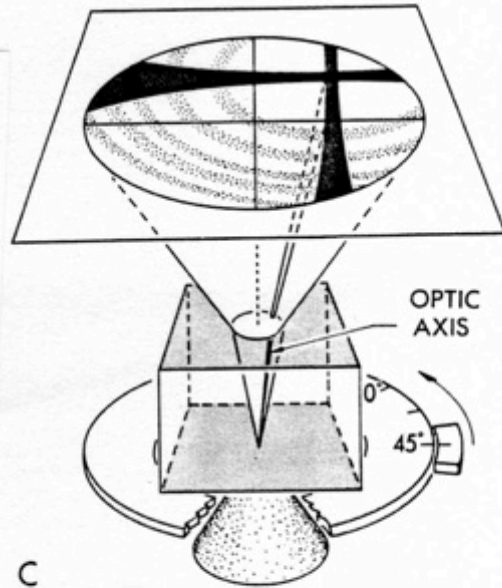
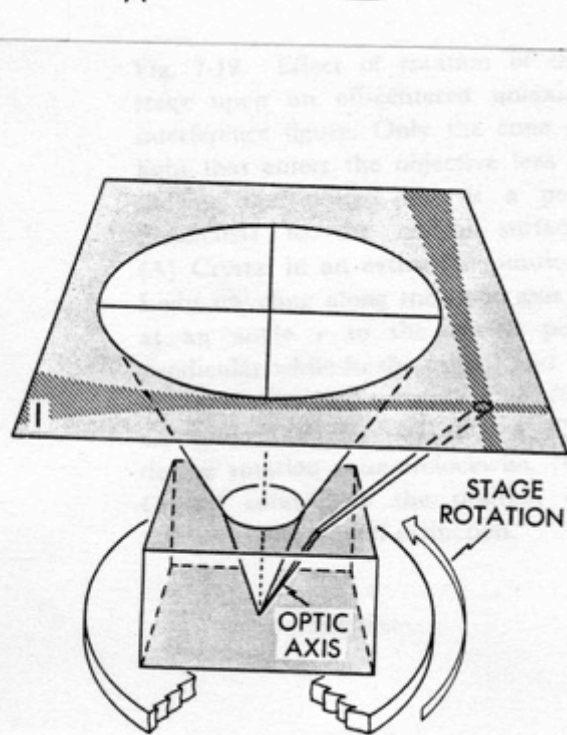
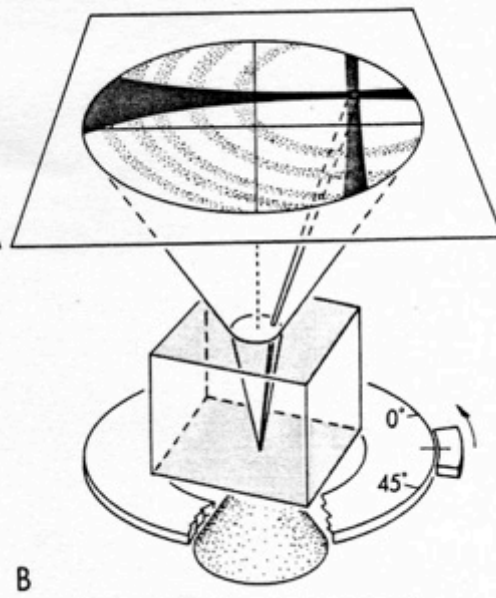
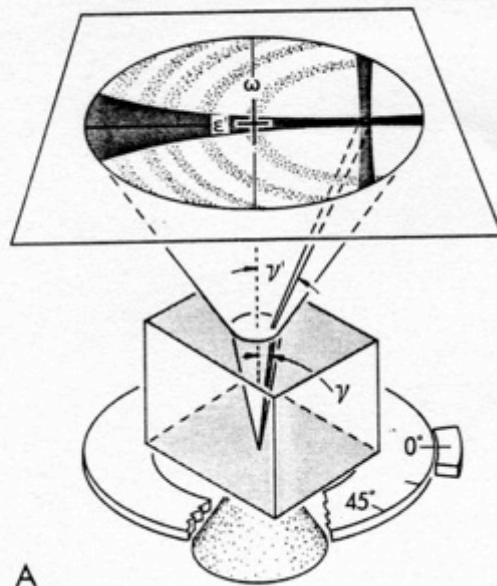


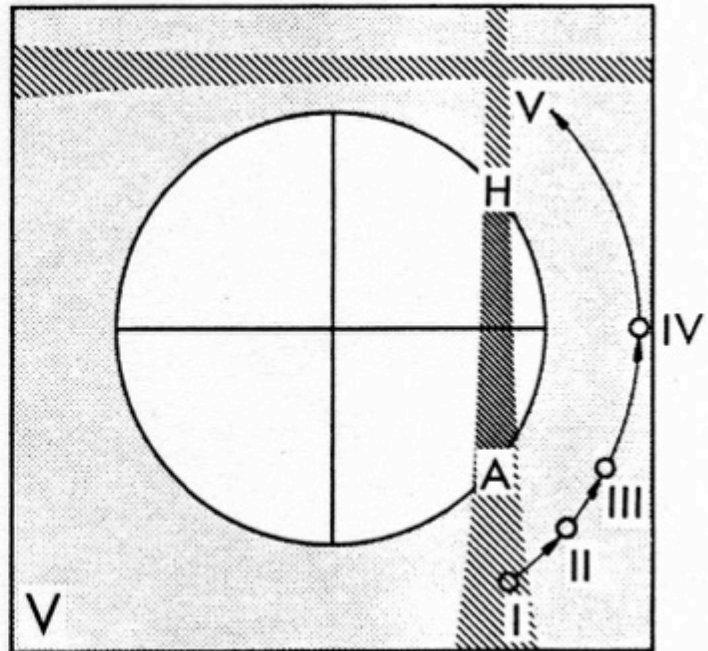
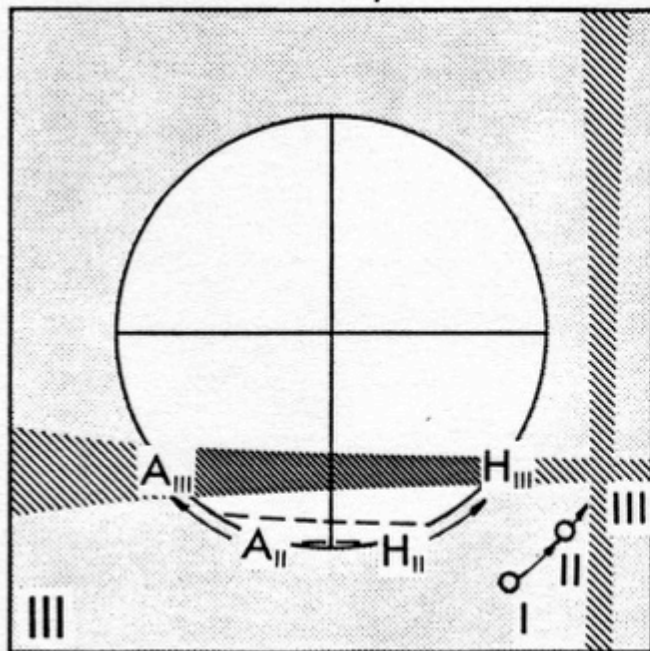
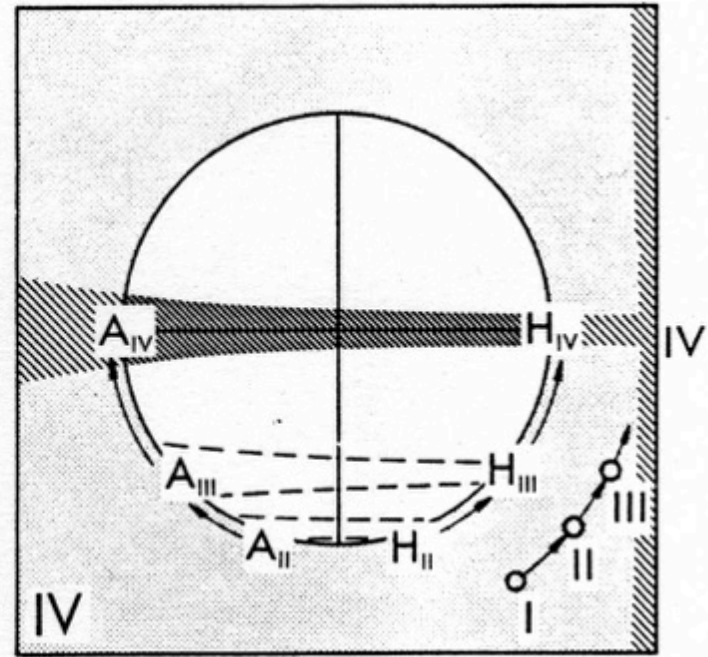
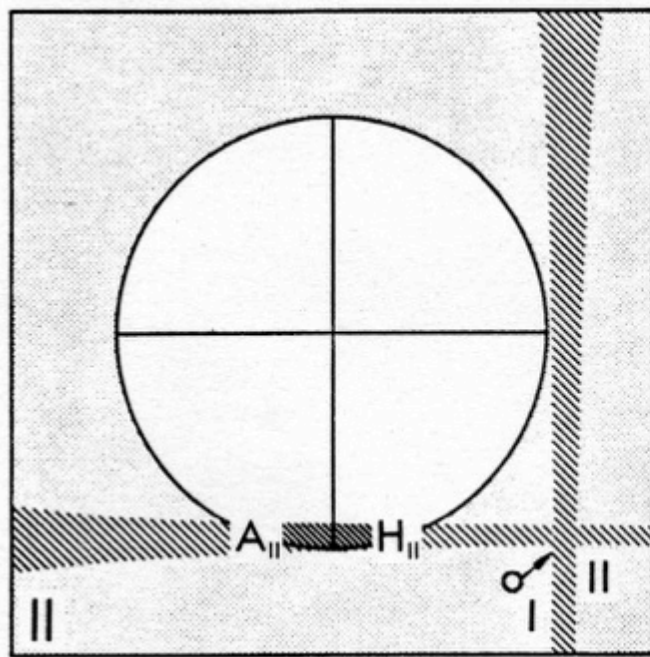
$$\text{RITARDO} = s(n_\gamma - n_\alpha)$$

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



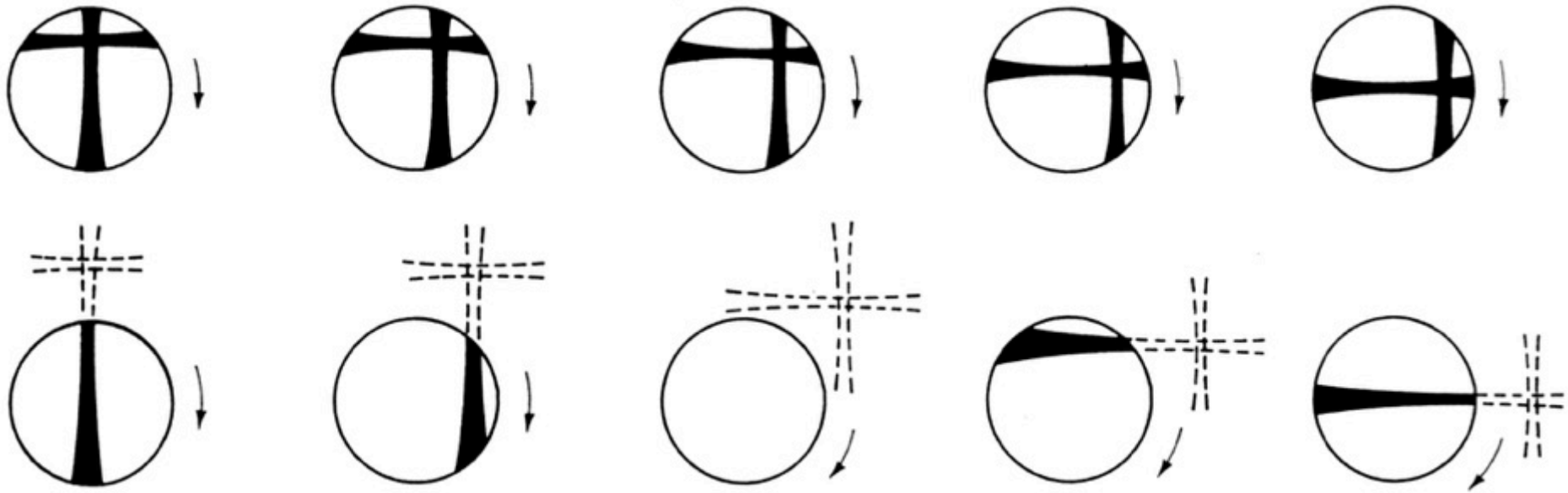
**RITARDO** distinto in vari ordini di colori (in nm dove  $1\text{nm} = 10^{-3}\mu = 10\text{\AA} = 10^{-7}\text{cm}$ )



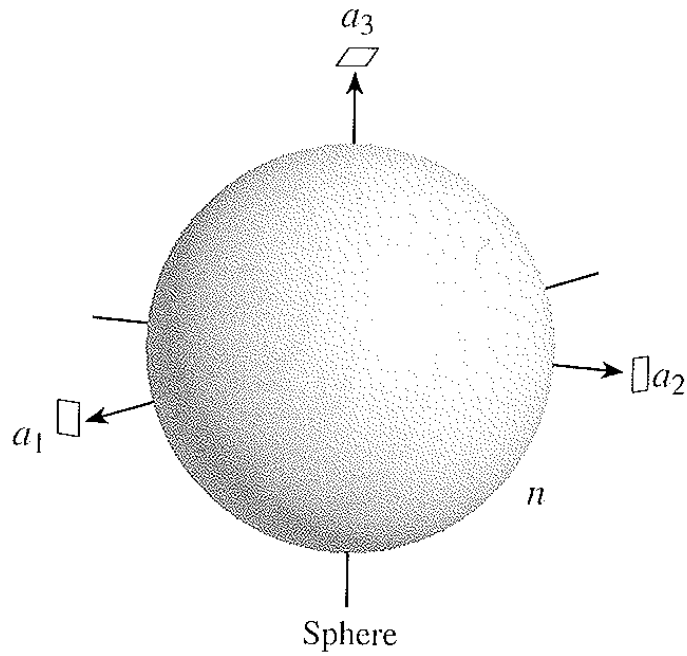


# CRISTALLO UNIASSICO

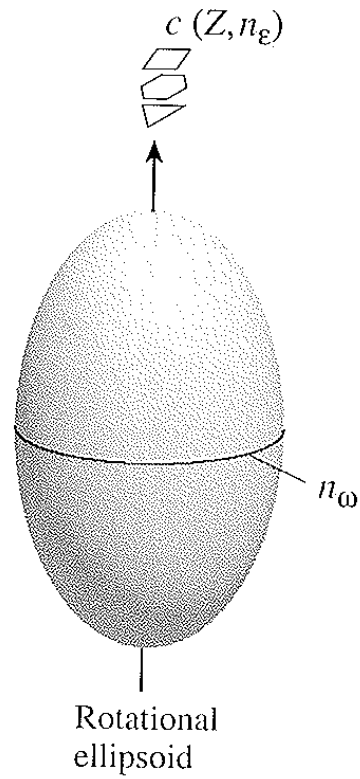
sezioni diversamente inclinate rispetto all' AO e per diverse rotazioni del piatto



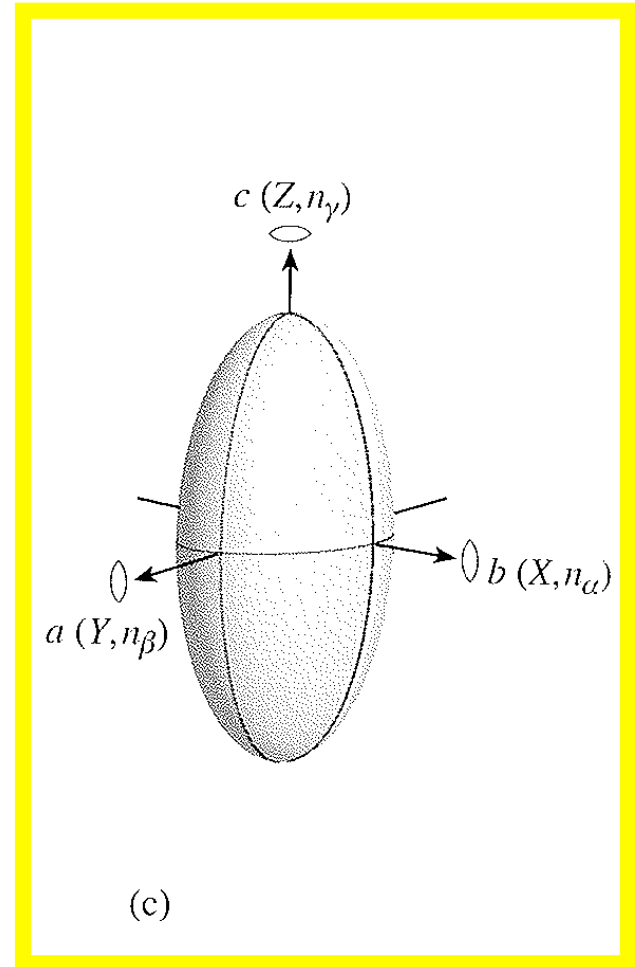
# Indicatrici Ottiche



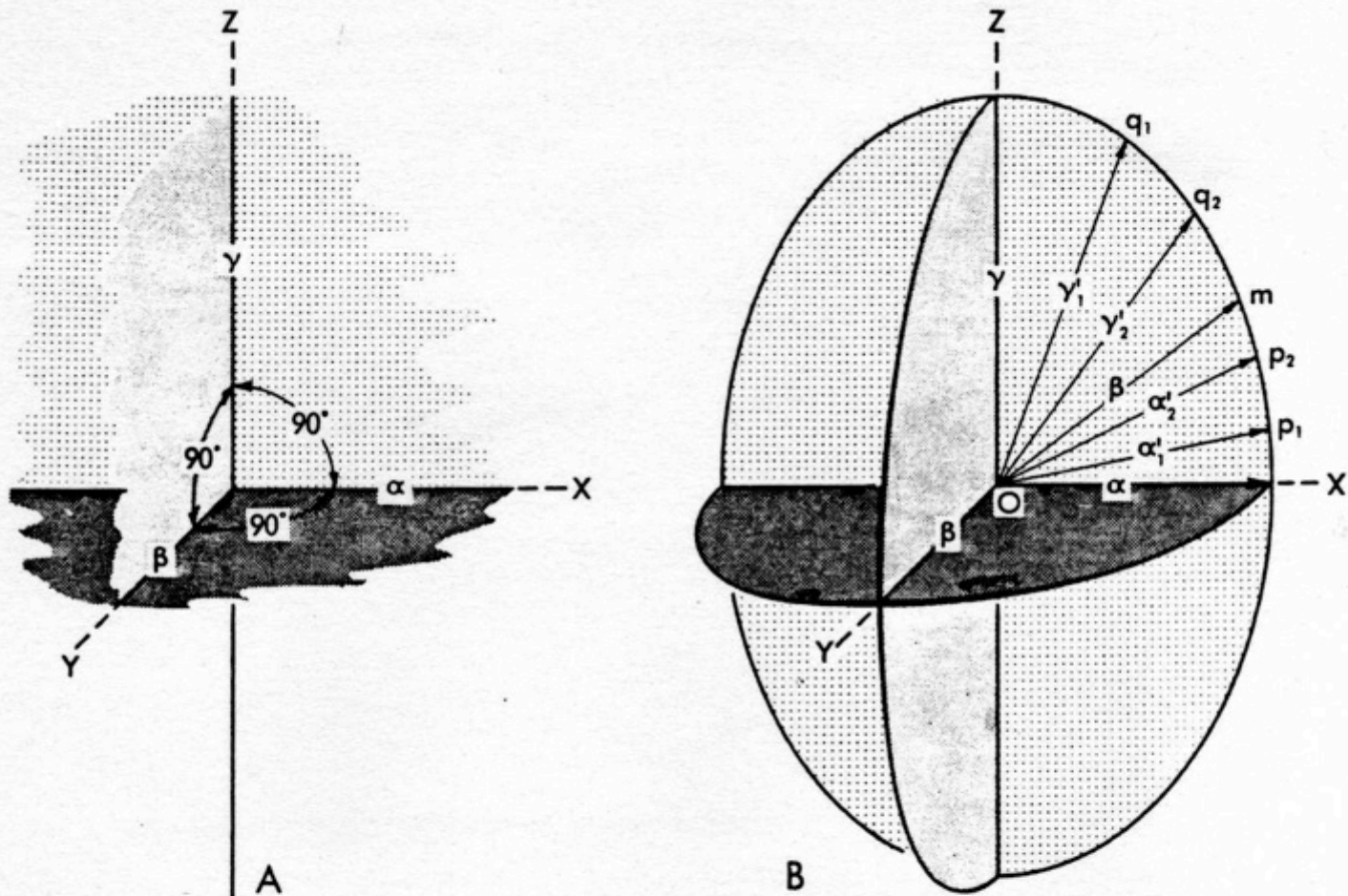
(a)



(b)

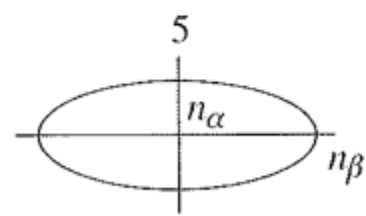
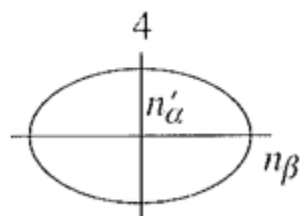
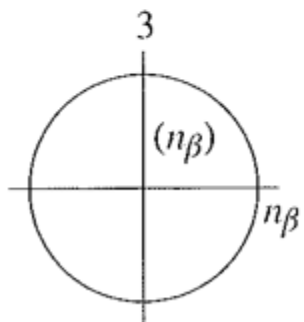
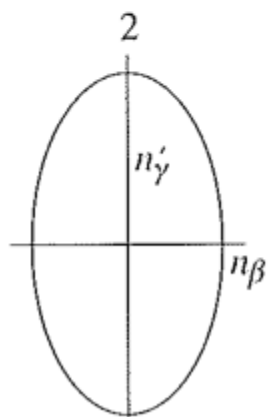
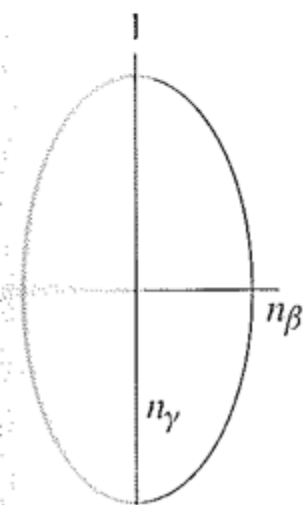
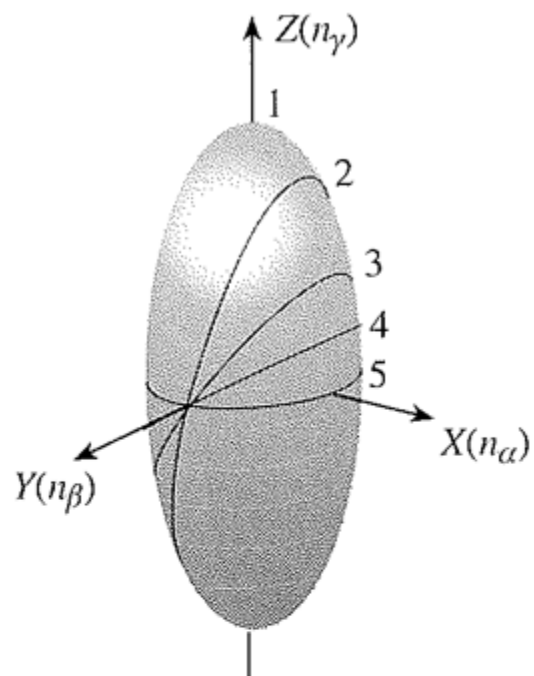


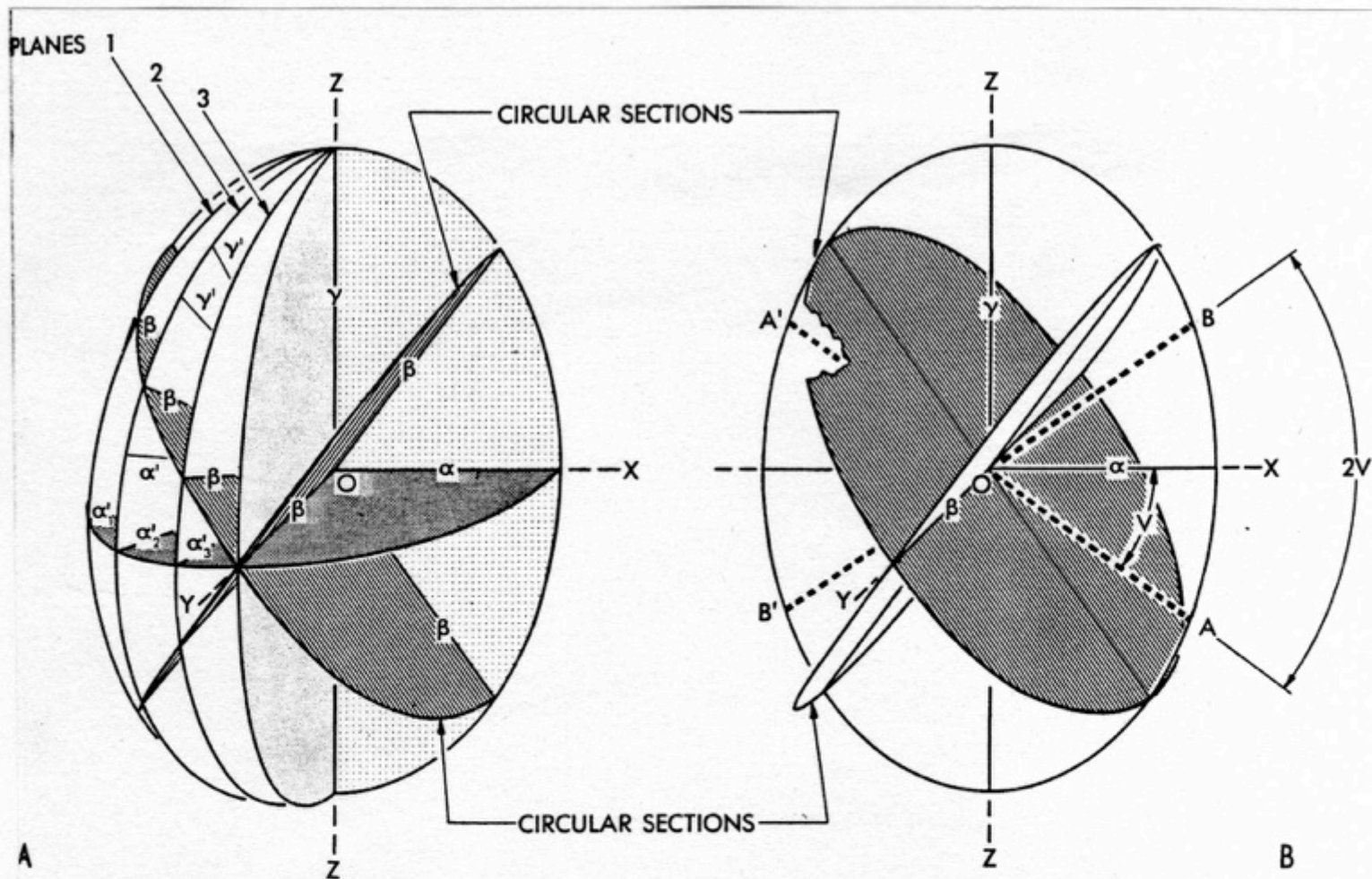
(c)



**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.

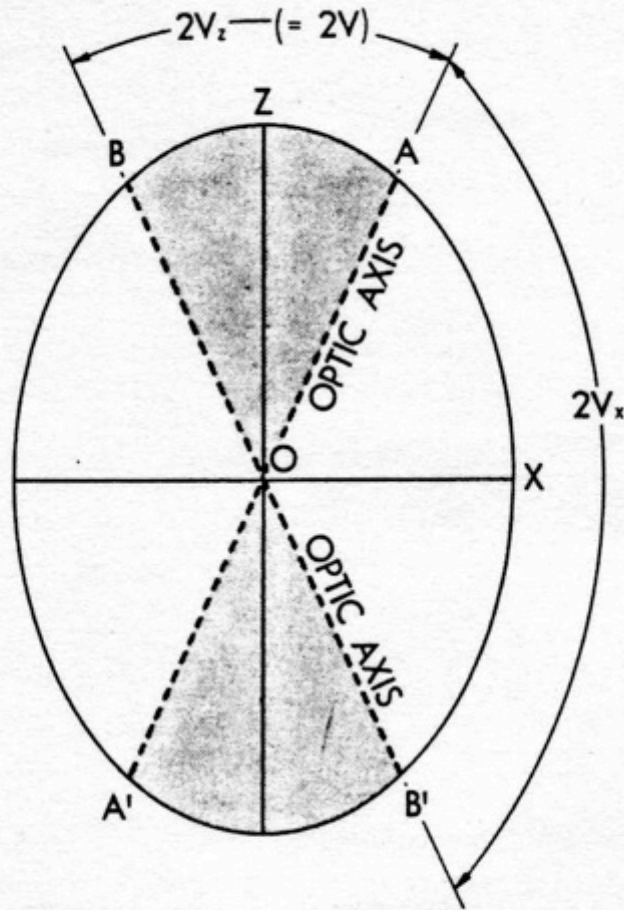




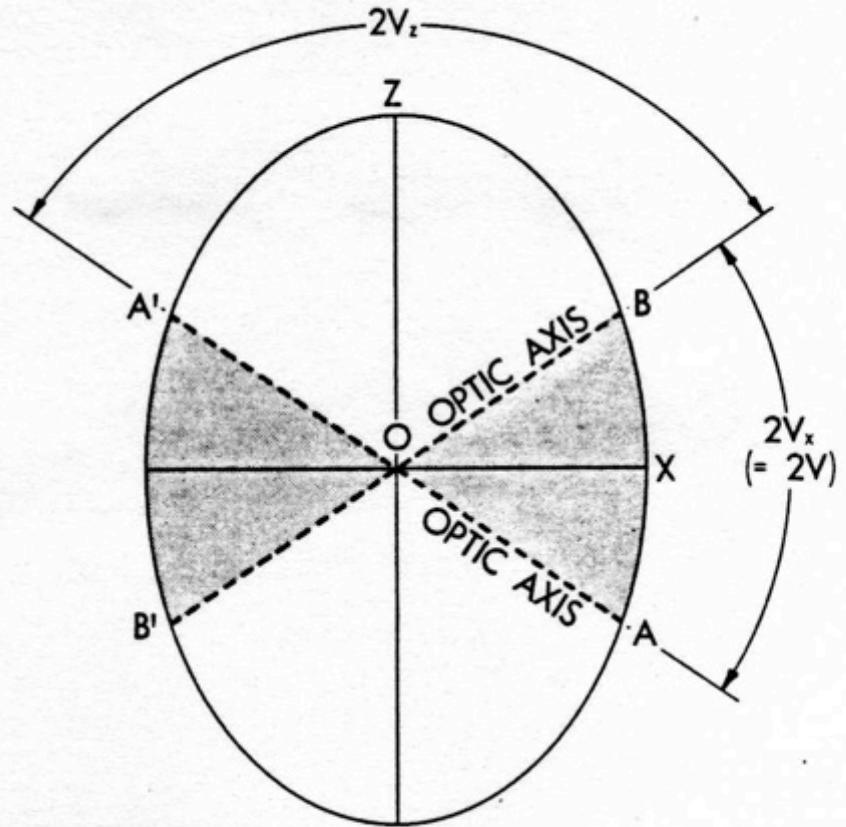


**Fig. 9-2.** (A) Variation of refractive index in a biaxial crystal as shown by ellipses (whose radii are proportional in length to the crystal's refractive index for light vibrating parallel to them). Planes 1, 2, and 3 are typical of the numerous ellipses that could be drawn to hinge on  $ZZ$ . All such ellipses contain one radius equal to  $\beta$  in length, these radii lying in the same planes (ruled). These planes, the circular sections, intersect in principal axis  $Y$ . (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.

+



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**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.

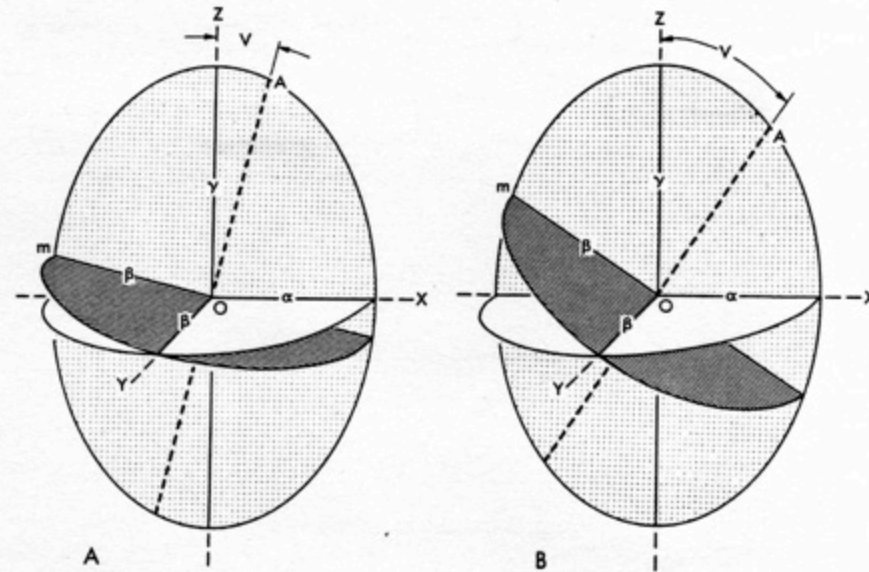


Fig. 9-5. The variation of  $2V$  in four crystals all possessing equal values of  $\alpha$  and  $\gamma$  but, from (A) to (D), increasing values of  $\beta$ . For simplicity only one circular section (closely ruled) and one optic axis ( $OA$ ) are drawn. Note the attendant increase in  $2V$  from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

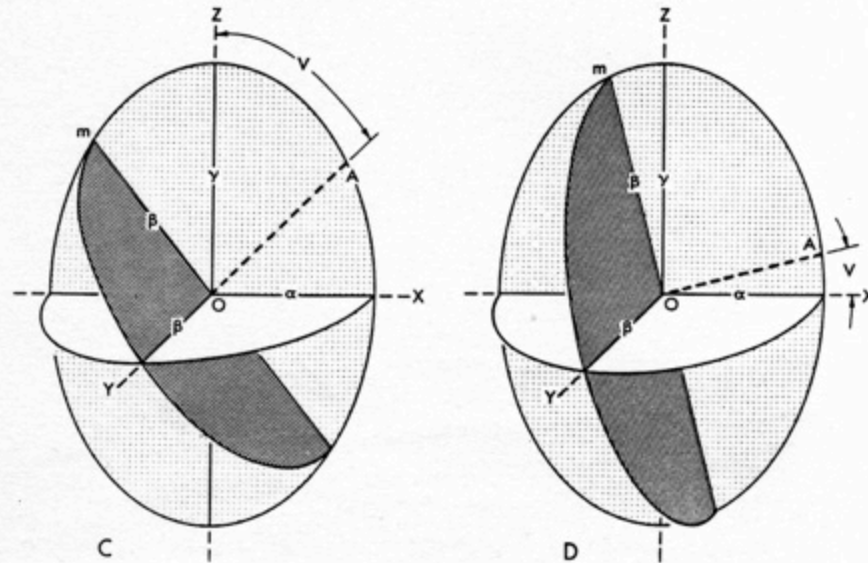
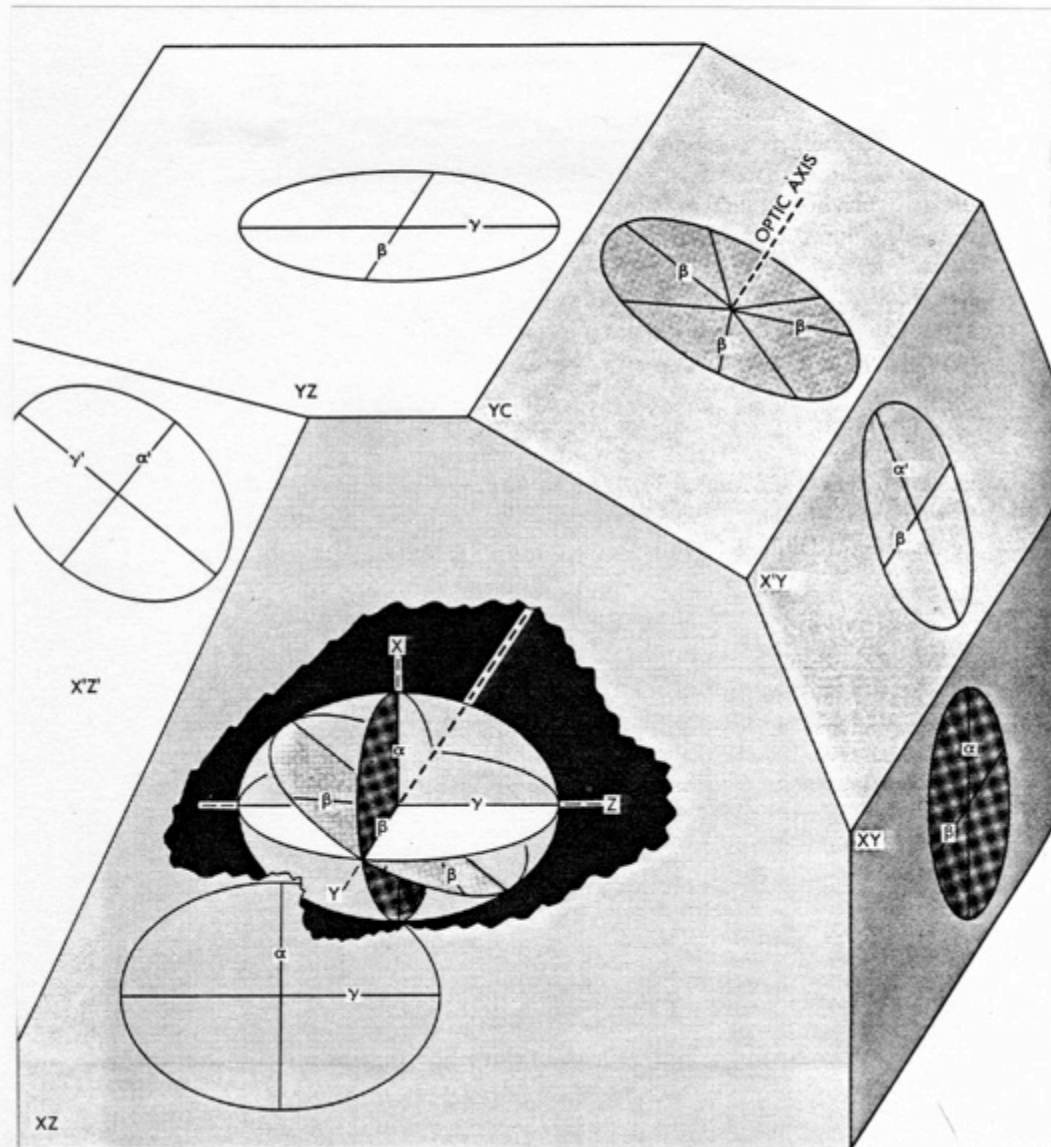
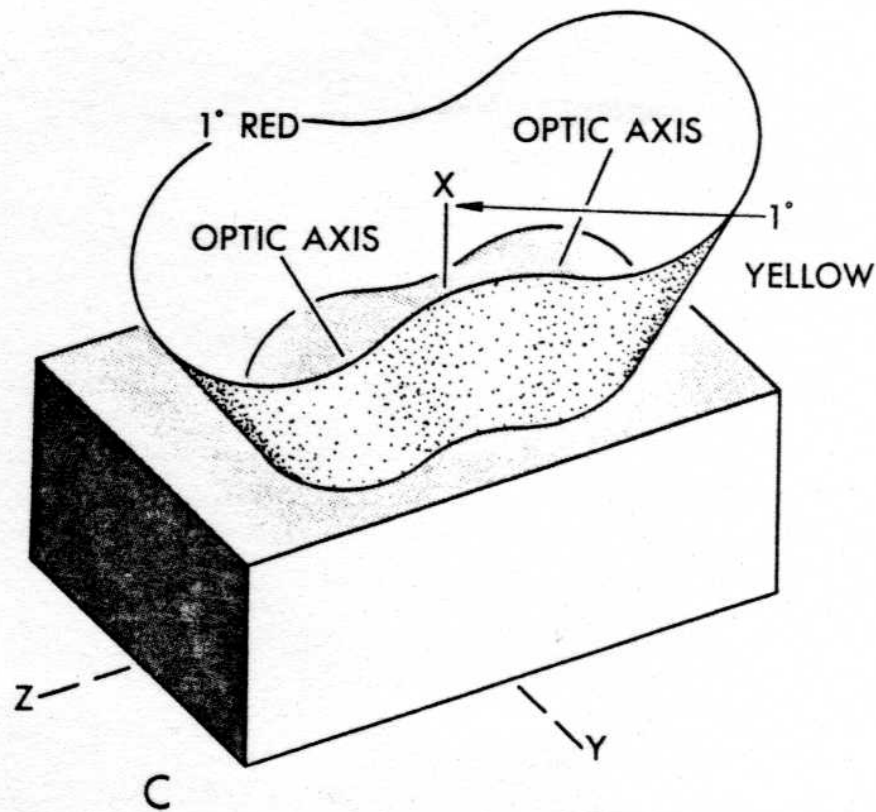
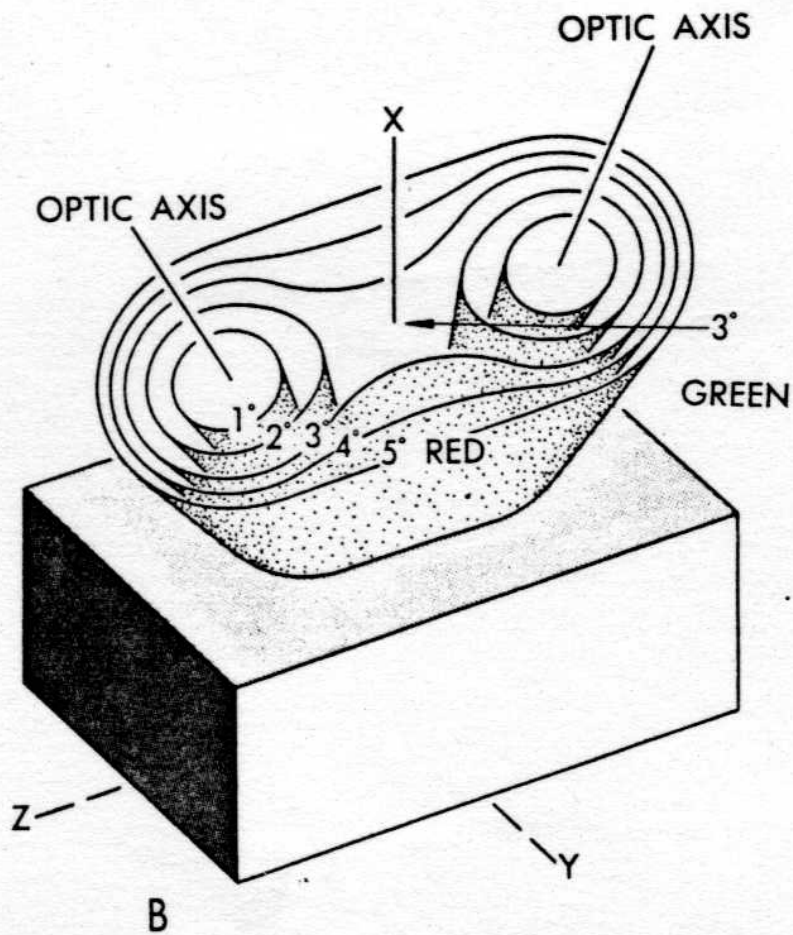


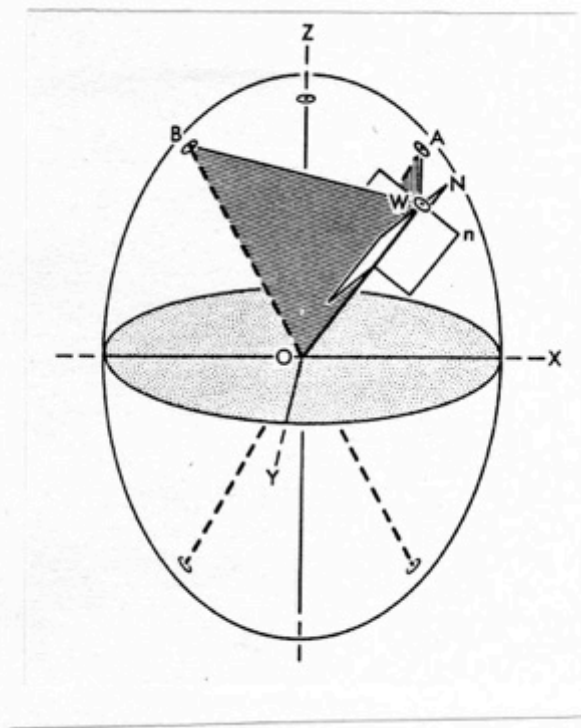
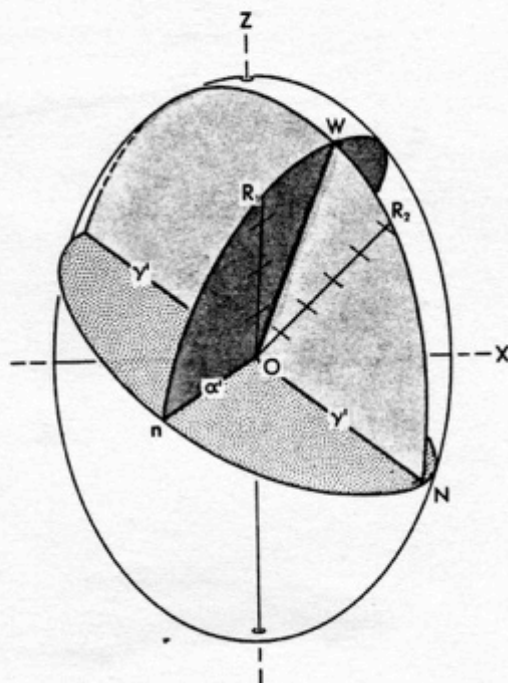
Fig. 9-9A. The vibration directions,  $WN$  and  $Wn$ , that are associated with wave normal  $OW$ , as obtained by the Biot-Fresnel rule. ( $OA$  and  $OB$  represent the two optic axes.)

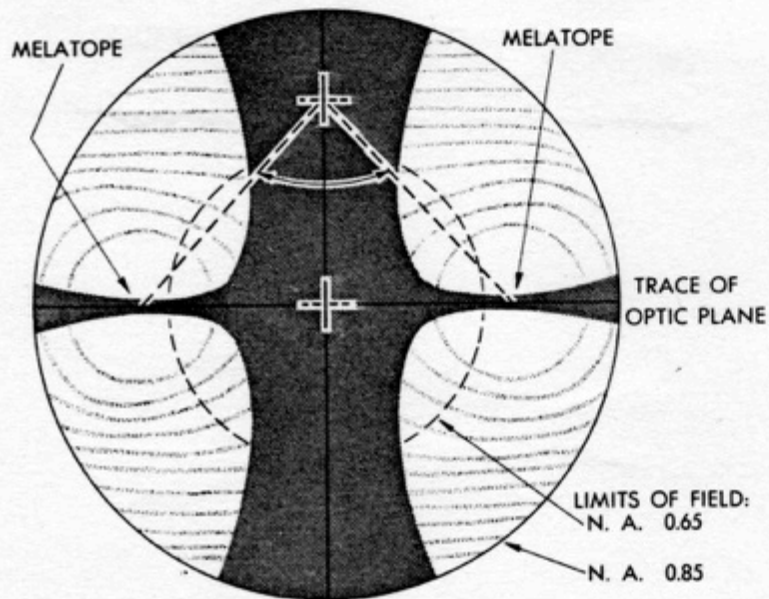




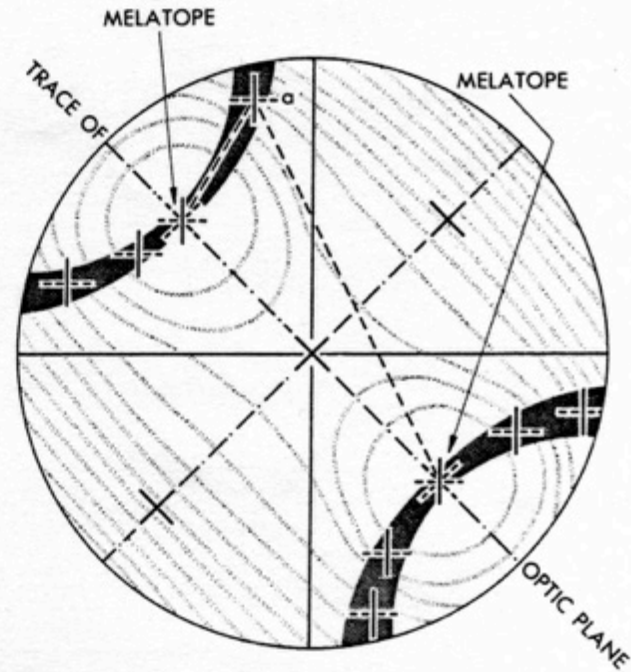
**Fig. 9-15B-C.** (B) Surfaces of equal retardation above a crystal of moderate to high birefringence. (C) Same for crystal of low birefringence.

**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.





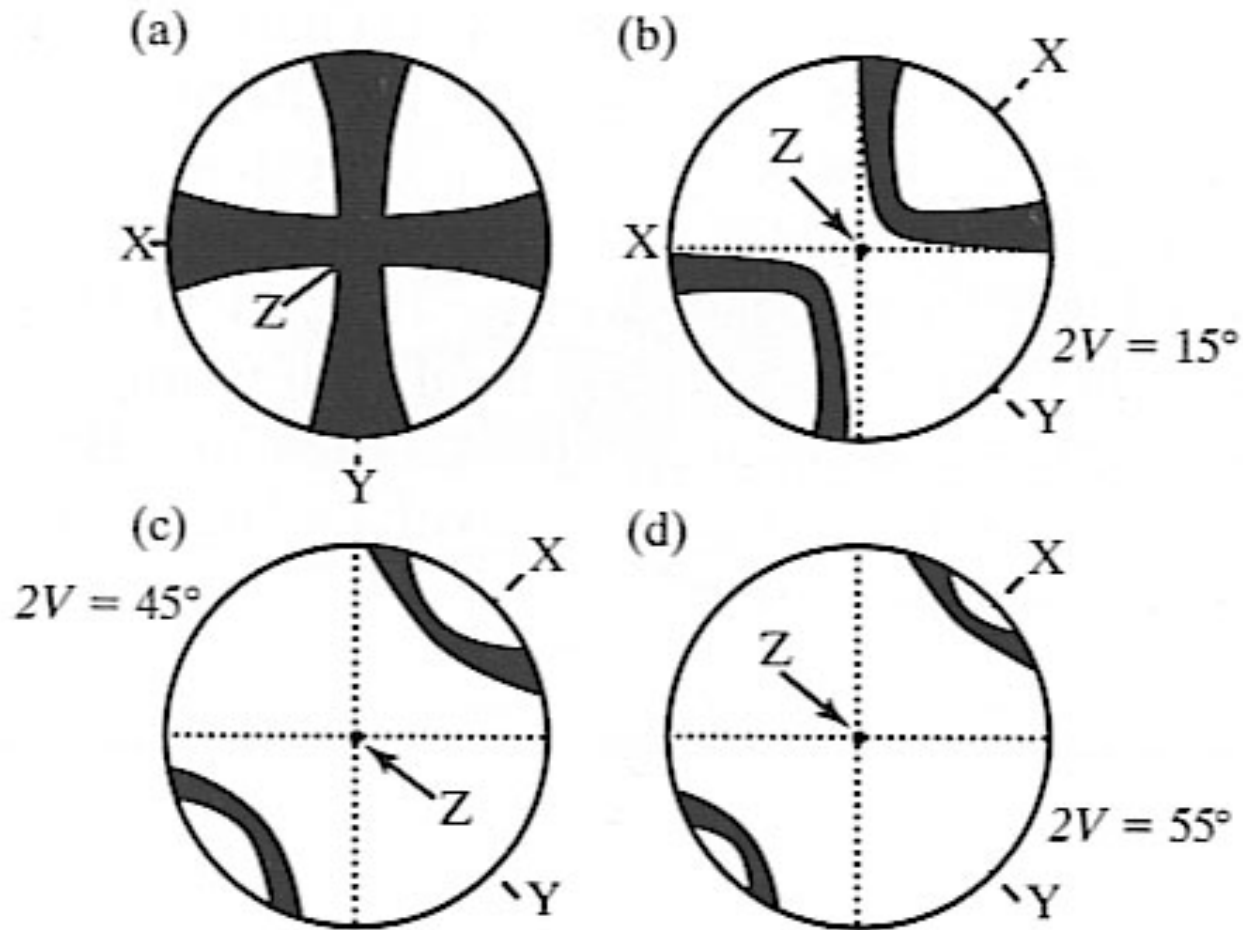
**Fig. 9-16B.** Fig. 9-16A as seen if the microscope stage is rotated 45 degrees counterclockwise. Extinction occurs in the areas where rays emerge that vibrate parallel to the polarizer. The dashed circle marks the limits of the field of view if an objective of N. A. 0.65 is used instead of one of N.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



**Fig. 9-16A.** Centered, acute bisectrix figure at 45 degrees off extinction position. The two-dimensional analog of the Biot-Fresnel law is applied to point *a* to determine (approximately) the privileged directions for rays emerging there. At several points in the field of view the privileged directions for the rays emerging there are also shown.



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



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

