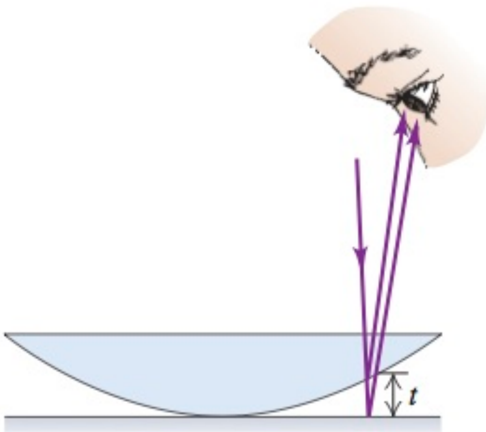
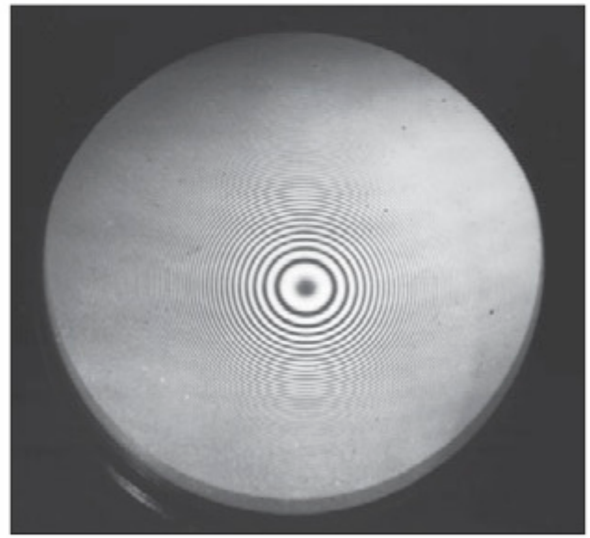
03. Arago and Biot.

Buchwald (1989), Chaps 3, 4.

1. Arago and Ring Polarization.

- *Newton's Rings*





Air film between a convex lens and a plane surface. The thickness of the film t increases as we move out from the center, giving a series of alternating dark and bright rings.

Contemporary (wave theory) Explanation:

Light/dark rings caused by constructive/destructive interference between rays reflected from both upper and lower surfaces of the "laminar" (air gap).

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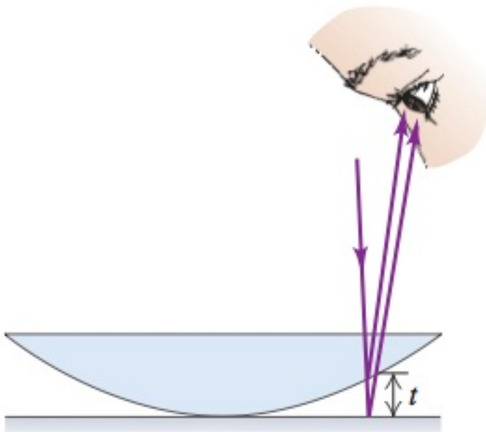
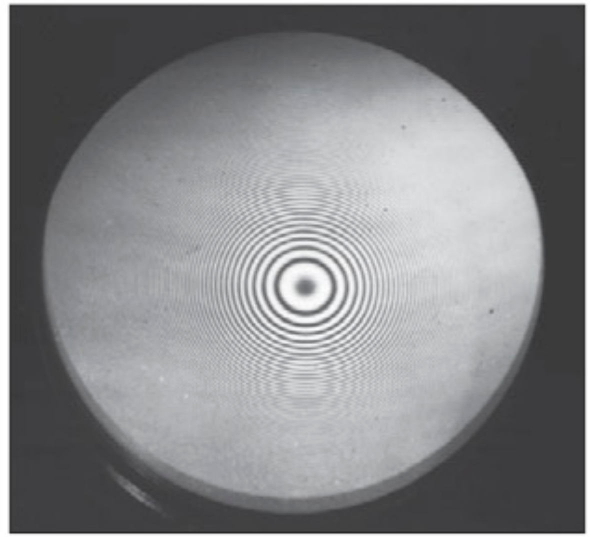




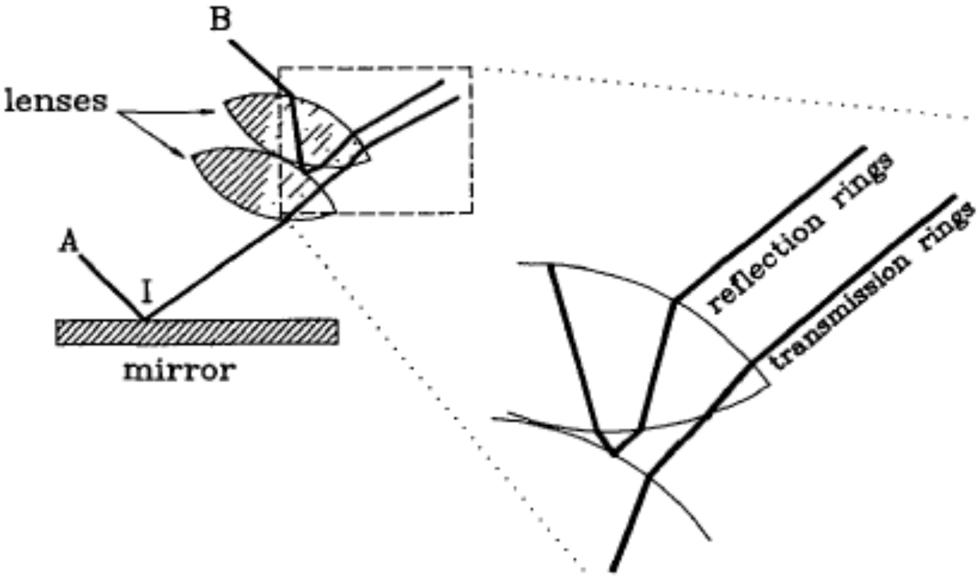
Air film between a convex lens and a plane surface. The thickness of the film t increases as we move out from the center, giving a series of alternating dark and bright rings.

Newton's Explanation:

- Each ray has inherent property, "fit", that causes it to be reflected or refracted.
- Ray refracts if distance traveled is nearer an even than odd number of fits; otherwise it reflects.
- *So*: Upper surface doesn't produce rings: rays that reflect off it are in every possible fit state.
- *And*: Lower surface produces rings: rays that reflect off it are all in a given fit state.

Arago observers polarization of Newton's rings (1811).

François Arago
(1786-1853)



- *Shine "natural" light on device.*
- *Portion A strikes mirror and then two lenses from below.*
- *Portion B strikes two lenses from above.*
- *Two beams emerge, one by reflection of B, the other by refraction of A.*
- *Beams pass through analyzing crystal.*

- When reflection ring beam passes through analyzing crystal, it splits into ordinary (O) and extraordinary (E) parts.
- *Arago observes*: O and E beams differ in intensity, and at polarizing incidence, one vanishes.
- *Thus*: Reflection ring beam is *fully polarized*.

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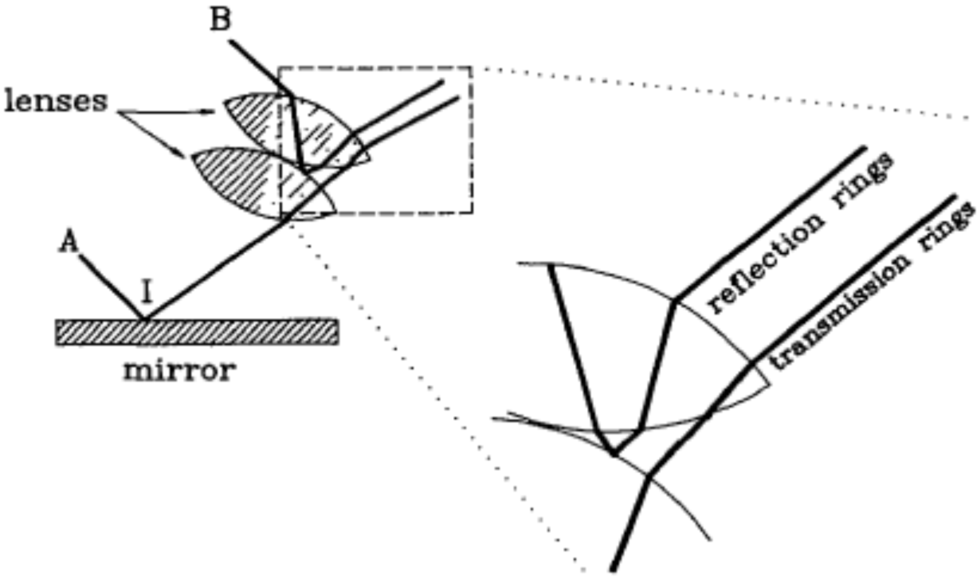

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- *Moreover*: The polarizing property affects the rays that form reflection rings in the same way it affects the reflected rays that do not form rings.
- *However*: The rings formed by refracted (i.e., trasmitted) rays are *not* polarized.
- *Arago's Conclusion*: Upper surface (and not, as Newton claimed, lower surface) governs production of the rings.

2. Arago and Chromatic Polarization.

"On examining, in calm weather, a very thin lamina of mica with the aid of a prism of Iceland spar, I saw that the two images projected on the atmosphere were not tinted with the same colors: one of them was greenish yellow, the second purplish red..."

"I recognized at the same time that a slight change in the inclination of the lamina with respect to the rays that traversed it caused the color of the two images to vary and that if, leaving the inclination constant and the prism in the same position, one turns the mica lamina in its own plane, one finds four positions at right angles where the prismatic images have the same strength and are perfectly white."

"Leaving the lamina immobile and turning the prism, one also sees each image successively acquire diverse colors and pass through white after a quarter-revolution. Further, for all positions of the prism and the lamina, whatever the color of one of the beams, the second always presented the complementary color, so that, in those points where the two images were not separated by the double refraction of the crystal, the mixture of these two colors formed white."

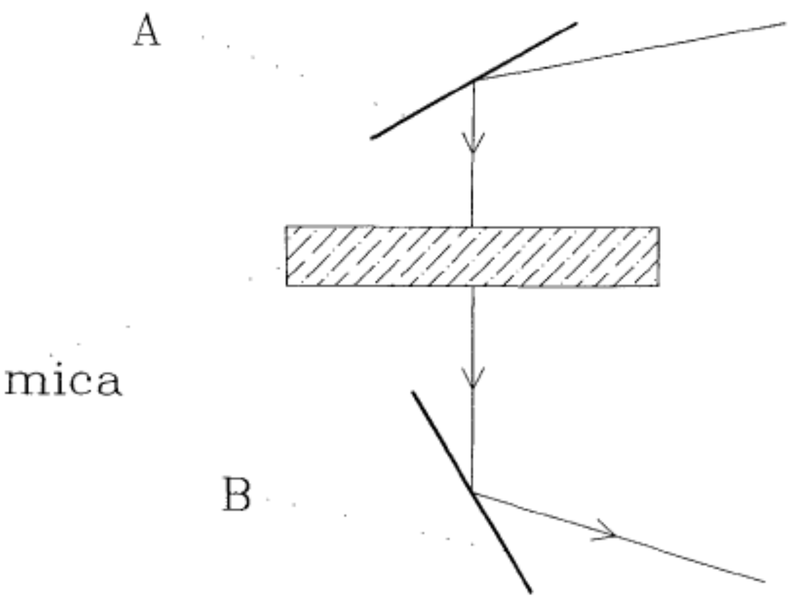
Selectionist Explanation:

"Given contemporary principles, there was only one general way to interpret the fact that on passing through a mica plate and then though an analyzer, polarized white light yields complementary-colored O and E beams: the common asymmetry of the rays in the incident beam must have been altered in a way that depends in some fashion on the rays' colors and on the orientation of the lamina in its own plane." (Buchwald, pg. 76.)

"...if very thin laminae of glass act on light both as thin laminae and as reflecting bodies of a certain thickness [act], one will easily account for the most extraordinary phenomenon of double refraction, on supposing that substances endowed with that property are formed of very thin laminae properly placed and separated from one another. The only thing remaining to explain will be the separation of the images."

- *In Other Words*: The reason doubly refracting bodies polarize light in opposite directions lies in their structure.

Arago's Rotary Ray Selector



- *Beam is reflected from mirror A at polarizing incidence and passes through mica lamina.*
- *Beam that emerges is reflected off mirror B at polarizing incidence.*
- *B is allowed to rotate about vertical axis.*

Arago observes:

- Image of A in B is tinted, and tint changes as B rotates about vertical axis.
- Tint reflected from B at given position is complementary to reflected tint at quarter rotation before or after.
- Four positions of mica for which image at B is white.

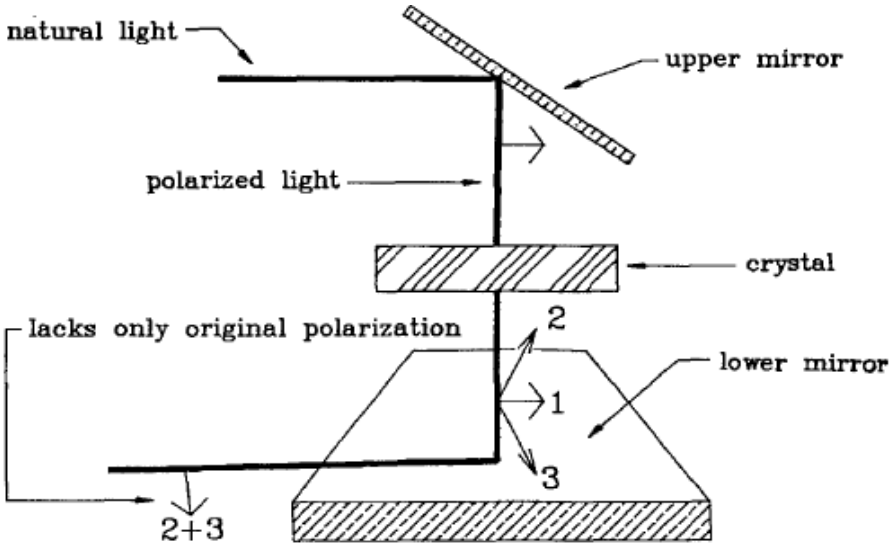
Explanation:

As B rotates, it reflects rays except for those polarized in direction perpendicular to its plane of incidence.

3. Biot and Mobile Polarization.

Jean-Baptiste Biot
(1774-1862)

Biot's Rotary Ray Selector



- *Arago's device:* plane of reflection of lower mirror is parallel to plane of polarization of upper mirror.
- *Biot's device:* plane of reflection of lower mirror is perpendicular to plane of polarization of upper mirror.

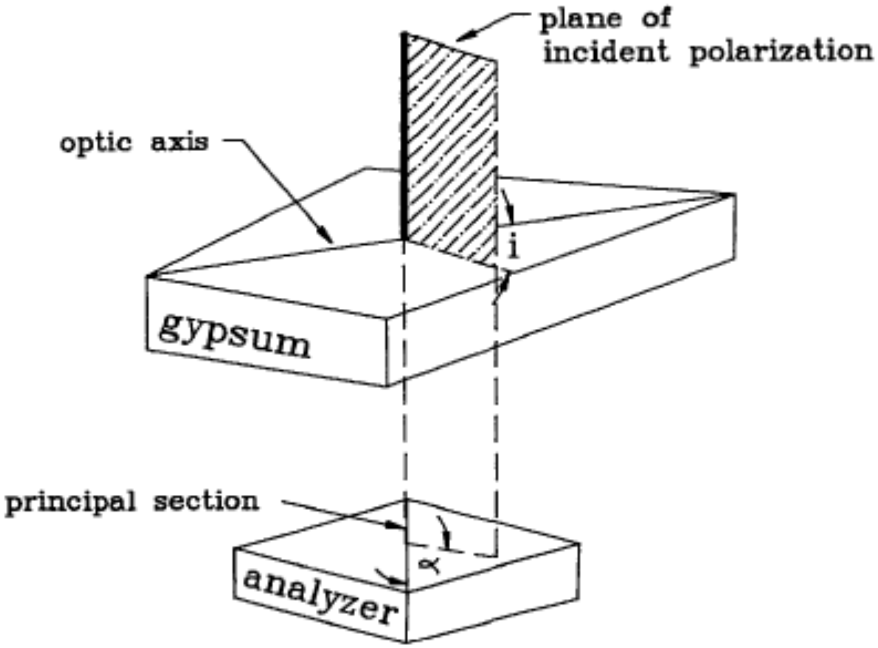
- *In Biot's device*: Lower mirror only reflects rays whose polarization has been deviated by lamina

- *Biot observes*: The tint of beam reflected by lower mirror does not change as lamina is rotated.

- *Why?* Reflected beam from upper mirror polarized ⊥ to plane of reflection.
- *So*: It's polarized || to plane of reflection of lower mirror.
- *So*: It's entirely refracted in lower mirror, in absence of lamina.

Biot's Hypothesis:
- Portion of beam passing through lamina that is deviated is doubly refracted.
- Resulting O and E beams have same tint.
- When lamina is rotated, at least one of O or E, or both, is always reflected.

Calculating the number of O and E rays

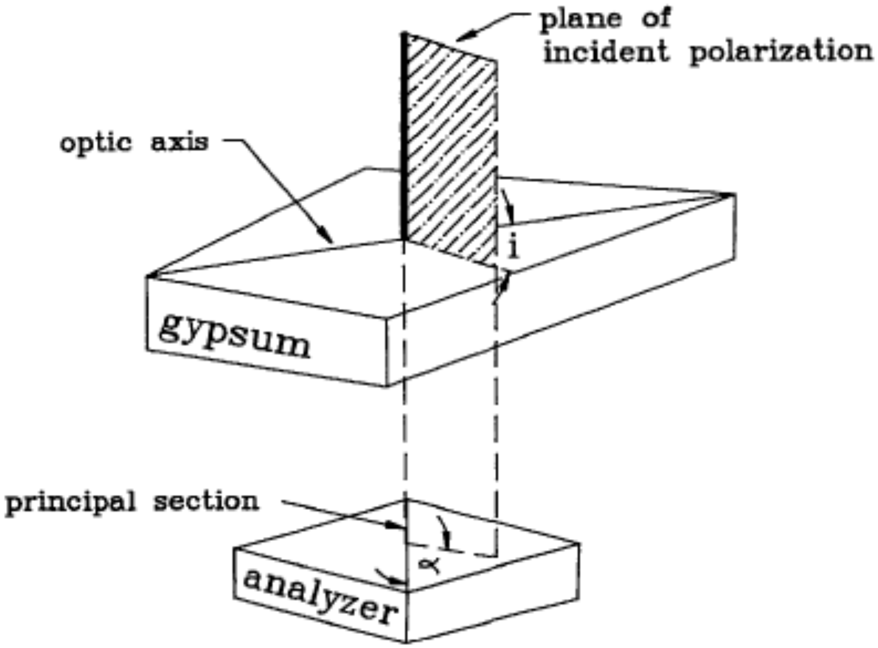


- *Replace lower mirror with crystal analyzer.*
- i = *angle between optic axis of lamina and plane of incident polarization.*
- α = *angle between principle section of analyzer and plane of incident polarization.*
- U = *# rays in incident beam that are unaffected by lamina.*
- A = *# rays in incident beam that are affected by lamina.*

- *Malus's Law sez*: #rays in O (*resp.* E) beam is proportional to square of the cosine (*resp.* sine) of angle between the plane of polarization of the incident beam and the polarizing axis of the material through which the beam passes (the optic axis of the lamina, or the analyzing crystal's principle section).

- *So*: Affected rays are doubly refracted by lamina and split into two bundles:
  - *Affected bundle* 1 *with* $A\cos^2 i$ *rays, polarized* $||$ *to lamina's optic axis.*
  - *Affected bundle* 2 *with* $A\sin^2 i$ *rays, polarized* $\perp$ *to lamina's optic axis.*

<u>*Calculating the number of O and E rays*</u>



- *Replace lower mirror with crystal analyzer.*
- i = *angle between optic axis of lamina and plane of incident polarization.*
- $\boldsymbol{\alpha}$ = *angle between principle section of analyzer and plane of incident polarization.*
- U = *# rays in incident beam that are unaffected by lamina.*
- A = *# rays in incident beam that are affected by lamina.*

- <u>*Thus*</u>: Analyzer receives three bundles of rays:
  - *Affected bundle* 1, *polarized at* $\alpha - i$ *to analyzer's principle section.*
  - *Affected bundle* 2, *polarized at* $90° - (\alpha - i)$ *to analyzer's principle section.*
  - *Unaffected bundle, polarized at* α *to analyzer's principle section.*
- <u>*Now*</u>: Each bundle doubly refracts in analyzer; so Malus's Law entails:

$$F_o = \textit{total \# O rays} = U\cos^2\alpha + A\cos^2 i\cos^2(\alpha - i) + A\sin^2 i\sin^2(\alpha - i)$$

$$F_e = \textit{total \# E rays} = U\sin^2\alpha + A\cos^2 i\sin^2(\alpha - i) + A\sin^2 i\cos^2(\alpha - i)$$

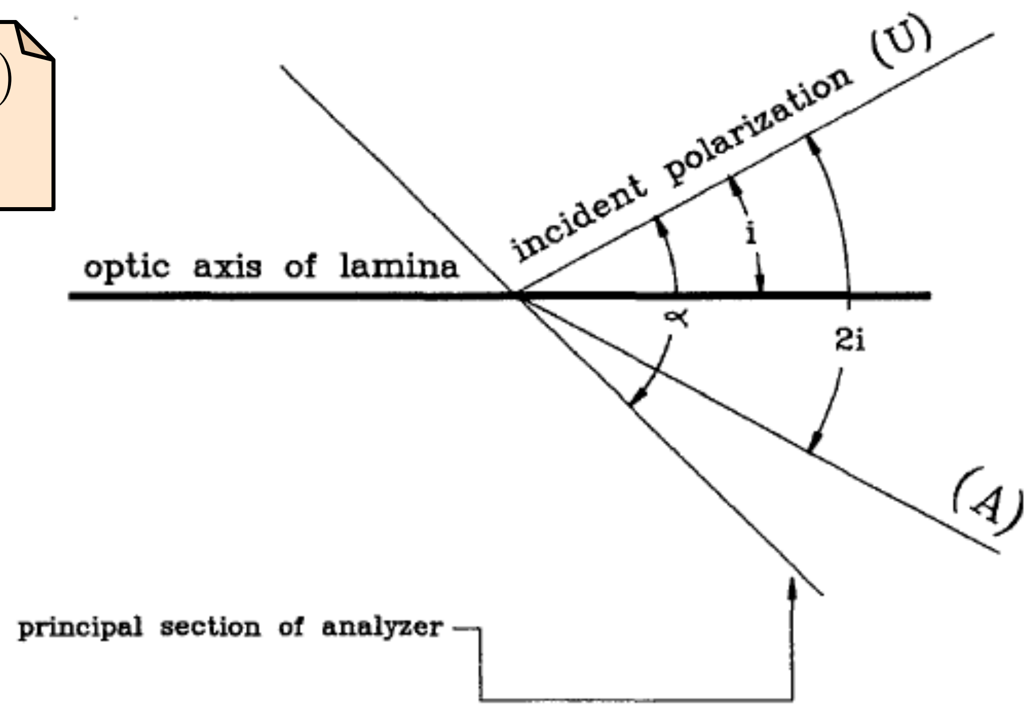
$$F_o = total\ \#\ O\ rays = U\cos^2\alpha + A\cos^2 i\cos^2(\alpha - i) + A\sin^2 i\sin^2(\alpha - i)$$
$$F_e = total\ \#\ E\ rays = U\sin^2\alpha + A\cos^2 i\sin^2(\alpha - i) + A\sin^2 i\cos^2(\alpha - i)$$

- *Note*: F_e is maximum for $\alpha = 0$, $i = 45°$:

$$F_o = U + A/2 = (U + A)/2 = half\ incident\ light$$
$$F_e = A/2$$

- *But*: Biot observes F_o vanishing at these angles.
- *Modified formula*:

$$F_o = U\cos^2\alpha + A\cos^2(2i - \alpha)$$
$$F_e = U\sin^2\alpha + A\sin^2(2i - \alpha)$$



- *Implications*:
  - *Unaffected bundle follows Malus's Law precisely.*
  - *Rays in affected bundle have their polarization rotated through angle $2i$ from one side of lamina's optic axis to the other.*

Biot's Theory of Oscillations ("Mobile Polarization")

"I hope to show that this phenomenon takes place by a succession of oscillations that the luminous molecules experience about their center of gravity, in virtue of attractive and repulsive forces that act on them."

"...comparing the consequences of the theory with experiment, one will see the rigorous analogy of these phenomena with colored rings, whence comes the succession of tints that crystals of this kind polarize when reduced to thin laminae..."

- *Claim*: Chromatic polarization is analogous to Newton's rings:
  - Color of rings varies with size of air gap.
- *Analogously*: Color of polarized beams varies with thickness of lamina.
- *In particular*:
  - Inside lamina, a ray's polarization oscillates between $0°$ and $2i$. The period of the oscillation is analogous to the fit length in Newton's rings.
  - When it exits lamina, a ray is either polarized along $0°$ or $2i$, depending on whether lamina's thickness causes ray to oscillate an integral number of times from the $0°$ direction or the $2i$ direction.