

Optical instruments, path differences and refraction

GRE · GRE Subject Test · GRE Physics

A gas cell in one arm of a Michelson interferometer is crossed twice. Counting only one passage halves the inferred refractive-index change.

Prerequisites: 3, 33.

- Calculate telescope magnification and grating resolving power
- Relate Michelson fringe counts to double-pass optical path changes
- Trace surface normals before applying Snell and reflection laws

Choose the system and model

For an ideal astronomical telescope adjusted for relaxed viewing at infinity, the objective forms its focal-plane image and the eyepiece collimates the emerging light. Lens separation is $f_{\text{objective}} + f_{\text{eyepiece}}$; angular magnification magnitude is $f_{\text{objective}}/f_{\text{eyepiece}}$. The usual two-converging-lens telescope produces an inverted image, represented by a negative signed angular magnification under a consistent convention. A finite final-image distance changes lens separation; do not use the infinity adjustment without checking the condition.

Use the governing relation

Resolving power $R = \lambda/\Delta\lambda$ describes the smallest distinguishable wavelength separation near λ . For an ideal diffraction grating in order m with N illuminated slits, $R = mN$. This is a resolution criterion, not simply the angular position formula $d \sin\theta = m\lambda$. Increasing illuminated slit count sharpens the principal peaks; increasing slit spacing mainly changes their angular locations. A measured $\lambda = 600 \text{ nm}$ and $\Delta\lambda = 3 \text{ nm}$ gives $R = 200$, independent of converting both lengths to metres because their ratio uses matching units.

Apply the conditions

Michelson interference depends on the optical path difference between the arms. If one arm contains a gas cell of geometric length L and index changes from n to 1 upon evacuation, a double passage changes path by $2L(n-1)$. If N fringes pass, the magnitude of this change is $N\lambda$, so $n-1 = N\lambda/(2L)$. For a moving mirror instead, displacement Δx gives path change $2\Delta x$. Fringes count phase cycles; one fringe is one wavelength of optical path, not one wavelength of mirror motion.

Check the conclusion

Snell's law $n_1 \sin\theta_1 = n_2 \sin\theta_2$ uses angles from the local surface normal. Reflection has equal incoming and outgoing angles from that same normal. In a rectangular block, normals of neighbouring faces are perpendicular: an incidence angle measured from one normal is complementary to the angle of that same ray from the other. Draw the ray and normals before substitution. For incidence from index n into air, total internal reflection occurs only when $\sin\theta > 1/n$; equality is the critical grazing case. A stated partly refracted ray must satisfy the transmission condition.

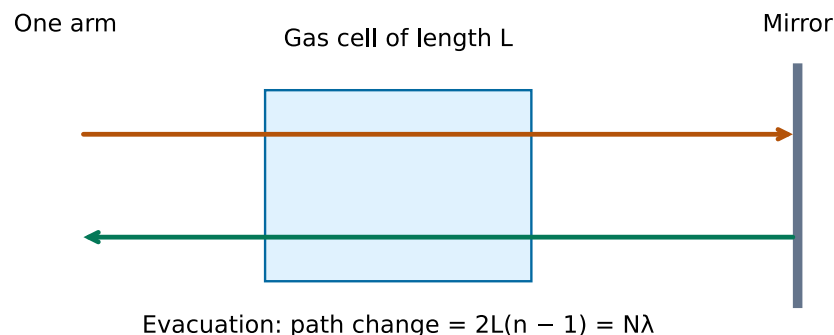
Worked method

A Michelson interferometer sends light twice through a gas cell of length L . Evacuation changes path by $2L(n-1)$. N fringes correspond to path change $N\lambda$.

$$n - 1 = \frac{N\lambda}{2L} = \frac{(120)(500 \times 10^{-9} \text{ m})}{2(0.10 \text{ m})} = 3.0 \times 10^{-4}.$$

Thus $n = 1.00030$. Moving a mirror is also double-pass; a fringe is not one wavelength of mirror motion.

Two passages through the same cell



Optical instruments, path differences and refraction: original GRE teaching diagram.

Check conditions and vocabulary

Use optical path, not just geometric distance. Refraction angles are measured from the normal of the actual surface, and telescope focal-length addition assumes a final image at infinity.

resolving power: Wavelength divided by the smallest resolvable wavelength separation.

optical path length : Geometric path weighted by refractive index along the ray.