Optical instruments, path differences and refraction

GRE undergraduate preparation · local supported objectives

Optical instruments, path differences and refraction

- Find the length and **angular magnification** 角放大率 of a telescope.
- Use the **resolving power** 分辨本领 of a grating.
- Count interferometer fringes, remembering the double pass.
- Use Snell's law, the **critical angle** 临界角 and **total internal reflection** 全反射.

The telescope

- The lenses are $f_o + f_e$ apart.
- The **angular magnification** is $|M| = f_o/f_e$, and the image is inverted.
- A larger objective collects more light and resolves finer detail; magnification alone does not.

Grating resolving power

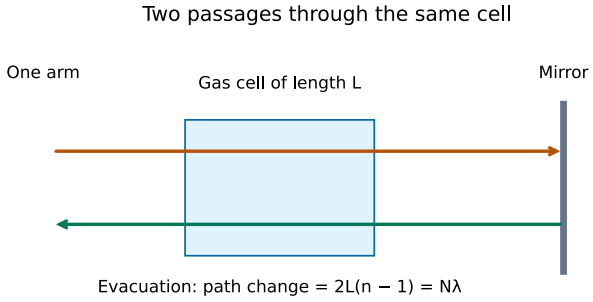
- N is the number of slits lit and m the order. More slits make the peaks sharper; the slit spacing only moves them.
- The sodium lines at 589.0 nm and 589.6 nm need $R \approx 1000$.

$$R = \frac{\lambda}{\Delta\lambda} = mN$$

Counting fringes

- Moving a mirror by Δx changes the path by $2\Delta x$: $N = 2\Delta x/\lambda$.
- A gas cell of length L in one arm, emptied or filled, changes the path by $2L(n-1)$.

Figure: Counting fringes



- Identify the axes, units, directions and the stated model.

Snell's law

- Use the normal of the surface the ray actually crosses; adjacent faces of a block have perpendicular normals.
- Light bends towards the normal when it slows down.

Total internal reflection

- Glass ($n = 1.5$) into air: $\theta_c = 41.8°$. Water ($n = 1.33$): $48.8°$.
- Optical fibres and prism binoculars use **total internal reflection**.

Worked example: a gas cell

- Path change: $2L(n-1) = N\lambda$.
- $n - 1 = \dfrac{80 \times 500 \times 10^{-9}}{2 \times 0.050} = 4.0 \times 10^{-4}$.
- Forgetting the double pass would give 8.0×10^{-4}, twice too large.

Worked example: telescope and grating

- $f_o = 80 - 16 = 64$ cm, so $|M| = 64/16 = 4$.
- To resolve the sodium lines in second order: $R = 589.0/0.6 = 982$, so $N \geq 982/2 = 491$ slits must be lit.
- A 600 nm pair 3 nm apart needs only $R = 200$.

Common errors

- Taking the telescope length as $f_o - f_e$ or the magnification as f_e/f_o.
- Thinking finer slit spacing alone improves resolving power.
- Forgetting the factor of 2 for the return trip in an interferometer.

Common errors (2)

- Measuring angles from the surface instead of the normal.
- Expecting **total internal reflection** going from air into glass.

Key terms

- **interferometer**: An instrument that splits light and recombines it to measure path differences.
- **angular magnification**: The ratio of the angle an image fills to the angle the object fills.
- **resolving power**: $\lambda/\Delta\lambda$, a measure of how close two wavelengths can be and still be separated.
- **critical angle**: The angle of incidence beyond which **total internal reflection** happens.

Check yourself

- A Michelson mirror moves 0.10 mm with 500 nm light. How many fringes pass?
- What is the **critical angle** from water ($n = 1.33$) into air?
- What resolving power separates 600 nm lines 3 nm apart?