Waves and optics

GRE undergraduate preparation · local supported objectives

Waves and optics

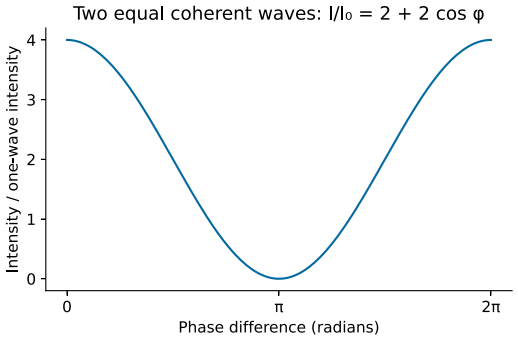
- Add **coherent** 相干的 waves by amplitude, then square for intensity.
- Turn a **path difference** 程差 into a phase difference.
- Use the double-slit, single-slit and thin-film conditions.
- Decide when ray optics is good enough.

Superposition: add amplitudes, then square

- Two equal coherent waves in phase: amplitude $2A$, intensity $4I_0$. In antiphase ($\varphi = \pi$): zero.
- Adding intensities would always give $2I_0$. That is right only for incoherent light, such as two separate lamps.
- Coherent sources keep a fixed phase relation; in practice they come from one source split in two.

$$I = 2I_0(1 + \cos\varphi)$$

Figure: Superposition: add amplitudes, then square



- $I = 2I_0(1 + \cos\phi)$: four times one wave in phase, zero in antiphase
- Read the axes and units first.

Path difference and the double slit

- Double-slit maxima: $d\sin\theta = m\lambda$, $m = 0, \pm 1, \pm 2, \ldots$
- On a distant screen, the fringe spacing is $\Delta y = \lambda L / d$. Narrower slit spacing gives wider **fringes**.
- With N slits (a grating), the maxima stay at $d\sin\theta = m\lambda$ but become much sharper.

Single-slit diffraction

- Minima at $a \sin\theta = m\lambda$ with $m = \pm 1, \pm 2, \ldots$ Note: $m = 0$ is the bright centre, not a minimum.
- The central maximum is twice as wide as the others: $2\lambda L/a$ on a screen.
- A narrower slit spreads the light more. In a double slit, this single-slit pattern is the envelope of the **fringes**.

Thin films

- Soap film in air: one reflection is shifted, so strong reflection needs $2nt = (m + \frac{1}{2})\lambda$.
- If both reflections are shifted (or neither), strong reflection needs $2nt = m\lambda$.
- Inside the film the wavelength is λ/n.

Rays or waves?

- With this sign convention, a real image has $d_i > 0$ and is inverted.
- A converging lens with the object inside f gives a virtual, upright, magnified image.

$$\frac{1}{f} = \frac{1}{d_o} + \frac{1}{d_i}, \qquad m = -\frac{d_i}{d_o}$$

Worked example: slits and screens

- Fringe spacing: $\Delta y = \dfrac{\lambda L}{d} = \dfrac{(6.0 \times 10^{-7})(2.0)}{3.0 \times 10^{-4}} = 4.0$ mm.
- One slit alone, width $a = 0.10$ mm: central maximum width $2\lambda L/a = 2(6.0 \times 10^{-7})(2.0)/(1.0 \times 10^{-4}) = 24$ mm.
- So about six **fringes** fit inside the central **diffraction** peak.

Worked example: a soap film

- Only the top reflection (air to soap) is shifted, so use $2nt = (m + \tfrac{1}{2})\lambda$ with $m = 0$.
- $t = \dfrac{\lambda}{4n} = \dfrac{532}{4 \times 1.33} = 100$ nm.
- A film much thinner than this reflects almost nothing, so it looks black.

Common errors

- Adding intensities for coherent waves.
- Using $m = 0$ as a single-slit minimum.
- Forgetting the half-wavelength shift on reflection from a denser medium.

Common errors (2)

- Using the vacuum wavelength inside a film instead of λ/n.
- Mixing sign conventions in the lens equation.

Key terms

- **coherent**: Having a fixed phase relationship over time.
- **path difference**: The difference in the distances two waves travel to the same point.
- **superposition**: Adding the displacements of waves that meet.
- **fringe**: One of the bright or dark bands in an interference pattern.

Check yourself

- Two coherent waves of intensity I_0 meet with a **path difference** of $\lambda/4$. What is the intensity?
- The slit spacing of a double slit is halved. What happens to the fringe spacing?
- An object is 30 cm from a lens with $f = 10$ cm. Where is the image?