PHY2208 Lecture 5

Thick lenses
Chromatic aberration
Fibre optics

Pedrotti & Pedrotti p. 62-65 and p. 102 (only)
Y&F Section 34-4
Pedrotti & Pedrotti p. 505-506

Real lenses are not 'thin'

Multi-element lenses may contain several individual lenses in combination.

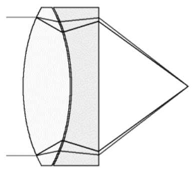
Any combination of lenses can be characterized by a single focal length provided object and image distances are Measured from the **principal planes** of the system.

Chromatic aberration

A material's refractive index is generally wavelength dependent (i.e. the material is **dispersive**). Usually $n(\lambda)$ decreases as λ increases.

Hence a converging lens brings blue light to a shorter focus than red light:

Chromatic aberration can be completely cancelled at any two wavelengths by using the **achromatic doublet**:



Fibre optics

Unlike lenses and mirrors, fibre optics relay light around **curved** paths.

Given that light travels in straight lines how is this possible?

Fibres rely on Total Internal Reflection (TIR):

Total internal reflection

Consider a ray propagating from a high to a low ref. index medium (e.g. glass to air):

Important new point: there is a **reflected** as well as a transmitted ray.

For small θ the reflected ray is normally of weak intensity.

Since $n_i > n_o$, Snell's Law:

$$\sin\theta_o = \frac{n_i}{n_o}\sin\theta_i$$

implies $\theta_o > \theta_i$

i.e. the transmitted ray is refracted **away** from the normal.

When

$$\sin\theta_i = \frac{n_o}{n_i} \Rightarrow \sin\theta_o = 1 \Rightarrow \theta_o = 90°$$

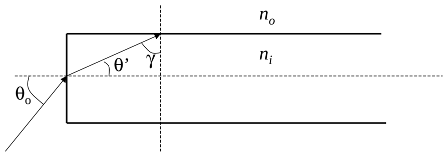
i.e. the transmitted beam no longer exists; the incident beam suffers TIR and is reflected with 100% efficiency.

The incident angle at which TIR occurs is called the **critical angle** θ_c.

$$\theta_c = \sin^{-1}\left(\frac{n_o}{n_i}\right) \quad \text{with} \quad (n_o < n_i)$$

A fibre-optic cable is a flexible tube of high *n* material surrounded by a 'jacket' or 'cladding' of lower *n* material. Light is guided down the tube by suffering repeated TIR. TIR is 100% efficient, so light can suffer **millions** of reflections without a significant loss of intensity.

Consider a long tube of material, refractive index n_i, diameter *d*, surrounded by material with refractive index n_o.



The **numerical aperture** (NA) of the fibre defines the largest angle of incidence θ_o a ray can have and be successfully transmitted.

$$\sin\theta'(=\cos\gamma) = \frac{n_o}{n_i}\sin\theta_o$$

TIR condition

$$\sin\gamma > \frac{n_o}{n_i} \quad \text{i.e.} \quad \cos^2\gamma < 1 - \frac{n_o^2}{n_i^2}$$

So

$$n_o \sin\theta_o < \sqrt{n_i^2 - n_o^2}$$

The **numerical aperture** is $n_o \sin\theta_o$

The **acceptance angle** is $2\theta_o$ and is the total angle over which light can be incident on the fibre and be transmitted.

You are now in a position to tackle **Question 8** on Problem Sheet 1.