revisely

Refraction, Diffraction and Interference

Interference

- Interference can be constructive or destructive - matching displacements are constructive, opposite are destructive. If the crest and trough are not of the same magnitude of displacement the destructive interference will not be total.
- For interference to occur the two waves must be **coherent** — having “the same wavelength and frequency, and a fixed phase difference”
- Interference type depends on **path difference**
    - Constructive interference: path difference = $n\lambda$
    - Destructive interference: path difference = $(n + \frac{1}{2})\lambda$

Young’s double slit experiment

- Showed the wave nature of light
- Illuminate two closely spaced slits using a suitable light source (Young used one slit prior to the double slit) — the two slits act as coherent sources of light.
- Alternate bright and dark fringes “Young’s fringes” are seen on a screen placed where the diffracted light from the slits overlaps
    - Fringes are evenly spaced and parallel to the double slit
- If the single slit prior to the double slit is too wide then each part of it produces a fringe pattern which is displaced slightly from the pattern due to adjacent parts of the slit — as a result the dark fringes of the double slit pattern become narrower than the bright fringes and the contrast is lost between the dark and light fringes.
- Fringes are formed as a result of interference of light from the two slits — a bright fringe is formed where light from each slit arrives in phase with each other, and a dark fringe results where the light waves are in antiphase.

Fringe separation, w, is the distance from the **centre** of one fringe to the centre of the other. The formula is only valid if w is much smaller than D.

$$w = \frac{\lambda D}{s}$$

- When measuring w, measure across several dark fringes from the centre of one to the centre of another — centres of dark fringes are easier to identify than those of light. Divide this measurement by the number of fringes measured across.
- Two loudspeakers connected to the same signal generator can be used to demonstrate interference as they are coherent sources of sound waves - can detect points of cancellation & reinforcement by ear, and Young's double slit equation can be used.

With white light, each component colour produces its own fringe pattern and each pattern is centred on the screen at the same position.

- Central fringe is white because every colour contributes at the centre of the screen
- Inner fringes are tinged with blue on the inside and red on the outside because the red fringes are more spaced out than the blue and the two fringe patterns do not overlap exactly
- Outer fringes merge into an indistinct background of white light because where the fringes merge different colours reinforce and therefore overlap.

Diffraction

- The gap needs to be similar in width to the wavelength. If it is much bigger then there will be no diffraction. Less diffraction occurs when waves pass through a wide gap than a narrow gap
- Diffracted waves spread of more if:
  - gap is made narrower, or
  - λ is much larger

When light passes through a single slit, we get an **interference pattern**. This consists of a central bright fringe, with dark and bright fringes alternating either side.

- Central fringe is twice as wide as other fringes
- Outer fringes are all the same width peak intensity decreases with distance from the centre, and outer fringes are much less intense than the central fringe
- Greater λ and/or narrower slit = wider fringes

$$\text{width of central fringe} \propto \frac{\lambda}{\text{slit width}}$$

- Thanks to the single-slit effect, Young's (double slit) fringes follow the same intensity distribution as for diffraction through a single slit

Diffraction gratings:

- When a parallel beam of monochromatic light is directed normally at a diffraction grating light is transmitted in certain directions only because:
  - Light passing through each slit is diffracted
  - Diffracted waves from adjacent slits reinforce each other in certain directions only (including the incident light direction) and cancel out in all other directions

$d \sin \theta = n\lambda$ where d = slit spacing, n = order (starting at 0)

Deriving the diffraction grating formula:

- The wavefront emerging from the slit reinforces a wavefront emitted n cycles earlier from the adjacent slit "above" it.
- This earlier wavefront must therefore have travelled a distance of $n\lambda$ from the slit - so the distance from the higher slit to the wavefront (the path difference) is $n\lambda$
- θ (angle of diffraction, between beam and zero order) is equal to angle between wavefront and plane of slits so $\sin \theta = \frac{n\lambda}{d}$ where d is the spacing of the two slits

$$d \sin\theta = n\lambda$$

- Increasing λ = fringes more spread out, increasing d = less spread out. $\theta < 90^\circ$ as sin 90° is the maximum possible.
- X-ray λ similar to the atom spacing in a crystalline structure, so X-rays form a diffraction pattern when directed at thin crystal - the spacing can be found from the diffraction pattern: "X-ray crystallography"
  - Diffraction gratings are used in spectrometers for studying the spectrum of light from any source and to measure light wavelengths very accurately.
- Maximum number of orders produced is given by $\frac{d}{\lambda}$ rounded down to nearest integer.
- Number of maxima observed is 2n + 1 where n is the greatest order

Types of spectra:

- **Continuous** - most intense part of the spectrum depends on the temperature of the light source - the hotter the light source the shorter the wavelength of the brightest part of the spectrum
- **Line emission** - glowing gas in a vapour lamp or discharge tube emits light at specific wavelengths so its spectrum consists of narrow vertical lines. The wavelengths are characteristic of the element that produced the light
- **Line absorption** - continuous spectrum with dark lines at specific wavelengths. Pattern of dark lines is due to the elements in the glowing gas — these elements absorb light of the same wavelengths they can emit so the transmitted light is missing these wavelengths. The atoms of the gas that absorb light then emit the light subsequently, but not necessarily in the same direction as the transmitted light.

Refraction

- Absolute refractive index is a measure of optical density

$$n = \frac{c}{c_s}$$

so the smaller the n of a substance, the greater the speed of light in that substance.

- Refractive index between two media, $_1n_2$ is a ratio of the speed of light in material 1 to that in material 2

$$_1n_2 = \frac{c_1}{c_2} = \frac{n_2}{n_1}$$

We can assume n at an air—substance boundary is the absolute n of a substance.

$$n_1 \sin\theta_1 = n_2 \sin\theta_2$$

- When a wave passes from a dense medium into a less dense medium, it bends away from the normal as it speeds up. The reverse is true.

Total internal reflection:

- The **critical angle** is the key to total internal reflection.
  - If light is incident at θc to the normal then the ray will exit along the flat surface
  - But if the angle of incidence is greater than θc, total internal reflection occurs.
  - Note that TIR will only occur at a boundary of higher n to lower n
- Rearranging Snell's law:

$$\sin\theta_c = \frac{n_1}{n_2}$$

- TIR is useful in **fibre optics**.
    - The **core** of the fibre has a **high** refractive index, but is surrounded by **cladding** of **lower** refractive index, which helps to protect the core from scratches (which could allow light to escape) and decreases θ_c to ensure TIR occurs.
- There are several issues encountered with fibre optics:
    - **Absorption -** loss in amplitude as light travels along the fibre. Can be reduced by increasing purity of the glass or using repeaters at frequent intervals.
    - **Modal dispersion -** light enters the fibre at different angles so can take different paths through the fibre, which results in **pulse broadening**. Can be mitigated by using monomode fibre.
    - **Material dispersion -** different wavelengths of light travel at different speeds through the glass (higher n for that λ, lower the speed). Using **monochromatic** light sources mitigates this issue.