Physics 1214 — Chapter 26: Interference and Diffraction

1 Interference and Coherent Sources

monochromatic light: light of a single color (wavelength).
interference: any situation in which two or more waves overlap in space.

Principle of superposition

When two or more waves overlap, the resultant displacement at any point and at any instant may be found by adding the instantaneous displacements that would be produced at that point by the individual waves if each were present alone.

in-phase: when two periodic motions are in step–their maximums and minimums coincide.

Constructive interference

Constructive interference of two waves arriving at a point occurs when the path difference from the two sources is an integer number of wavelengths:

$$r_2 - r_1 = m\lambda \quad (m = 0, \pm 1, \pm 2, \pm 3, ...).$$

Destructive interference

Destructive interference of two waves arriving at a point occurs when the path difference from the two sources is a half-integer number of wavelengths:

$$r_2 - r_1 = \left(m + \frac{1}{2}\right)\lambda \quad (m = 0, \pm 1, \pm 2, \pm 3, ...).$$

coherent: light from secondary sources derived from a primary source with a definite, constant phase relation.

2 Two-Source Interference of Light

Constructive and destructive interference, two slits

Constructive interference occurs at angles θ for which

$$d \sin\theta = m\lambda \quad (m = 0, \pm 1, \pm 2, ...).$$

Similarly, destructive interference (cancellation) occurs, forming dark regions on the screen, at points for which the path difference is half-integral number of wavelengths, $(m + \frac{1}{2})\lambda$:

$$d \sin\theta = \left(m + \frac{1}{2}\right)\lambda \quad (m = 0, \pm 1, \pm 2, ...).$$

Constructive interference, Young's experiment

$$y_m = R\frac{m\lambda}{d} \quad (m = 0, \pm 1, \pm 2, ...).$$

Destructive interference, Young's experiment

$$y_m = R\frac{\left(m+\frac{1}{2}\right)\lambda}{d} \quad (m = 0, \pm 1, \pm 2, ...).$$

The distance between adjacent bright bands in the pattern is inversely proportional to the distance d between the slits. The closer together the slits are, the more the pattern spreads out. When the slits are far apart, the bands in the pattern are closer together.

3 Interference in Thin Films

When a wave traveling in a medium a is reflected at an interface between this material and a different material b, there may or may not be an additional phase shift associated with the reflection, depending on the refractive indexes n_a and n_b of the two materials.

- if the second material b has a greater refractive index than the first n_a ($n_b > n_a$) the reflected wave undergoes a half-cycle phase shift during reflection
- if the second material b has a smaller refractive index than the first n_a ($n_b < n_a$) there is no phase shift.

Constructive interference, thin films

$$\boxed{2t = m\lambda \quad (m = 0, \pm 1, \pm 2, ... \text{ and } t \text{ is film thickness})}$$

Destructive interference, thin films

$$\boxed{2t = \left(m + \frac{1}{2}\right)\lambda \quad (m = 0, \pm 1, \pm 2, ...)}$$

Newton's rings: circular interference fringes formed when monochromatic light is incident on a thin film of air between a convex surface of a lens and a plane glass plate.

4 Diffraction

diffraction: interference patterns formed from a imperfectly sharp edge
Fresnel diffraction (near-field diffraction): both the point source and the the screen are at finite distances from the obstacle forming the diffraction pattern.
Fraunhofer diffraction (far-field diffraction): the source, obstacle, and screen are far enough away that all lines from the source to the obstacle can be considered parallel and all lines from the obstacle to a point in the pattern can be considered parallel.

There is no fundamental difference between *interference* and *diffraction*.

5 Diffraction from a Single Slit

Dark fringes, single slit

Where a is the slit width,

$$\sin\theta = \pm\frac{m\lambda}{a} \quad (m = \pm 1, \pm 2, ...).$$

In the "straight ahead" direction ($\sin\theta = 0$) is a *bright* band; in this case, light from the entire slit arrives in phase. It is wrong to put $m = 0$ in this equation. The central bright fringe is wider than the others.

VERY COMMON PHYSICS APPROXIMATION! If θ is very small,

$$\boxed{\sin\theta \approx \theta}$$

6 Multiple Slits and Diffraction Gratings

Increasing the number of slits in an interference experiment while keeping the spacing of adjacent slits constant gives interference patterns with the maxima in the same positions as with two slits, but progressively sharper and narrower.
diffraction grating: an array of a large number of parallel slits, all with the same width a and spaced equal distances d between centers with a maxima given by

$$d\sin\theta = m\lambda \quad (m = 0, \pm 1, \pm 2, ...).$$

7 X-Ray Diffraction

x-ray diffraction: diffraction pattern formed from x-rays scattered (absorbed and re-emitted) by individual atoms in a crystal.
Bragg reflection: constructive interference from a whole crystal lattice from many different d's and many sets of angles.
Bragg condition: $2d\sin\theta = m\lambda$ where ($m = 1, 2, 3$)

8 Circular Apertures and Resolving Power

First dark ring from a circular aperture

Where aperture diameter is D,

$$\sin\theta_1 = 1.22\frac{\lambda}{D}.$$

Airy disk: the central bright spot formed from a diffraction pattern of an aperture.

Rayleigh's criterion

The minimum angular separation of two objects that can barely be resolved by an optical instrument is called the **limit of resolution**, θ_{res} of the instrument:

$$\theta_{res} = 1.22\frac{\lambda}{D}$$

resolving power or resolution: sharpness of an image.

9 Holography

holography: a technique for recording and reproducing an image of an object without the use of lenses.
hologram: a photographic record of an interference pattern formed by light scattered from an object and light coming directly from the source.