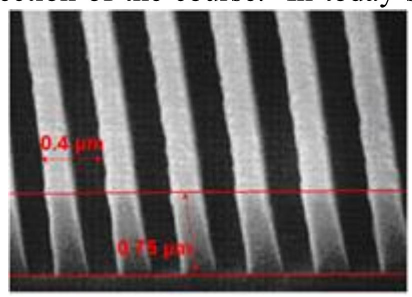
PHYS 1301

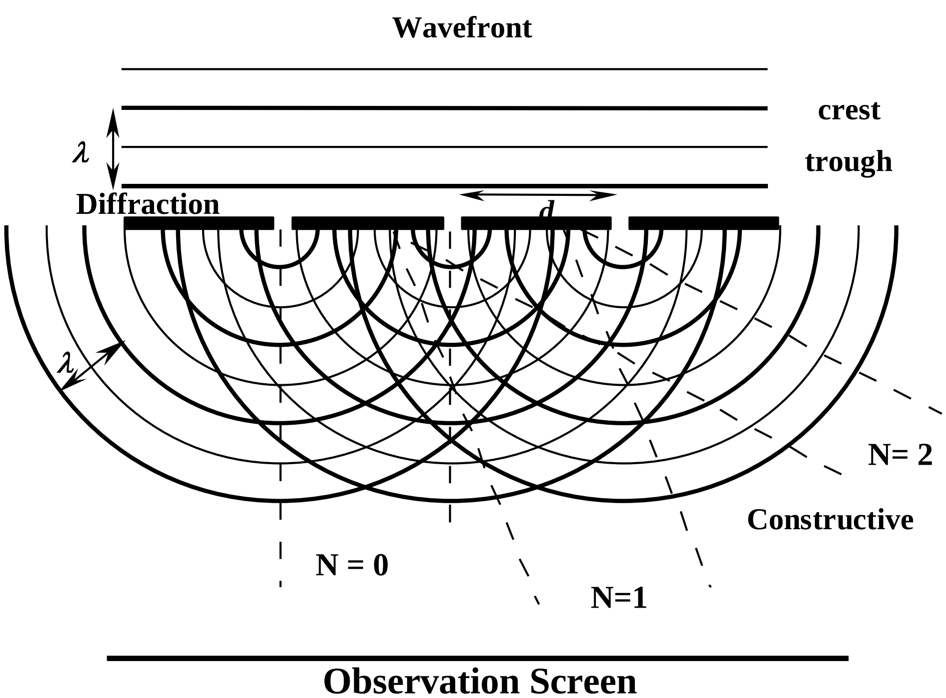
Laser Diffraction

Introduction

Diffraction basically means "spreading out", while interference is a pattern that emerges when waves collide. You may have already seen a demonstration of interference with light waves of a certain color passing through 2 slits in the lecture section of the course. In today's lab, you will use visible light waves to observe diffraction and interference by shining onto a large series of slits (apertures) that are separated from one another by a very small distance *d*, comparable to the wavelength of that wave. Such a series of apertures is called a "diffraction grating". You will use interference measurements to then calculate the wavelength of light waves and momentum of individual photons, quantities that are far too small to measure directly, and then verify Heisenberg's Uncertainty Principle.



A close-up of a diffraction grating

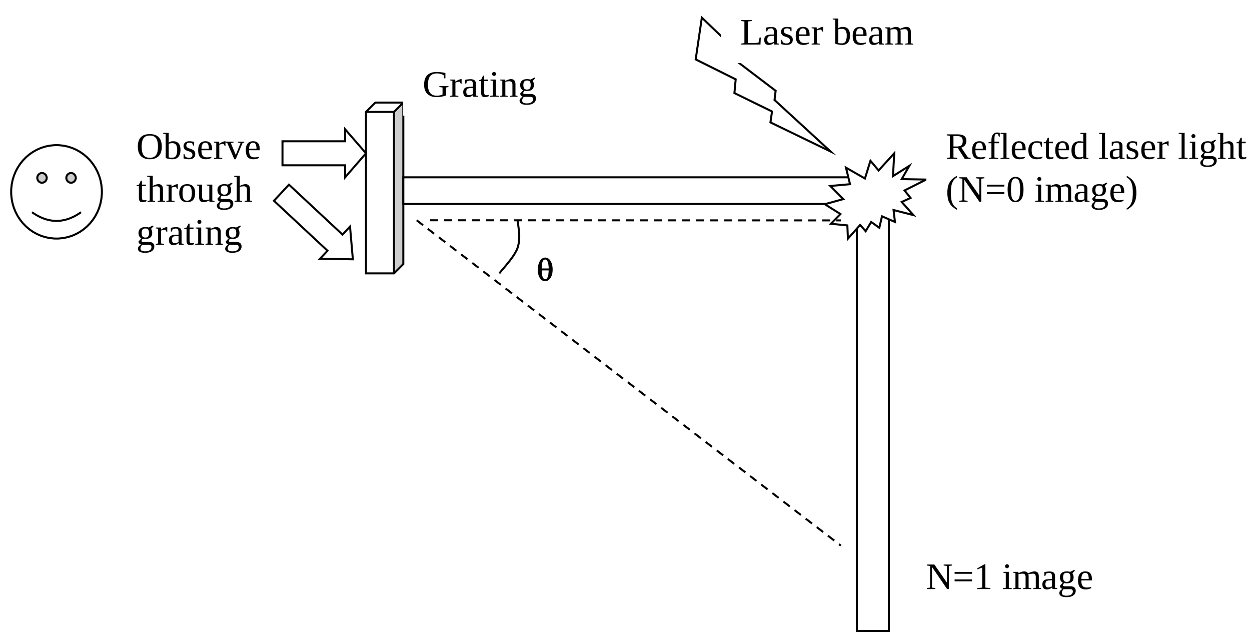


If we imagine light as similar to a water wave, with wavecrests (wavefronts) that move perpendicular to themselves, when a wavefront is incident upon the diffraction grating, parts of the wavefront are removed and each aperture serves as a source for a new wavefront that spreads out (diffracts). This is illustrated in the plan-view figure above. Since each of these sources is driven by the initial wave front, all the sources are in phase (meaning they all crest or trough at the same time when leaving their aperture). However, by the time the waves collide at some point on an observation screen behind the grating, they may be out of phase with one another because they have travelled different distances to that point. If all the peaks or all the troughs of the waves are still synchronized in time there, we say that at that point there is “constructive interference.” We see a bright region. If, on the other hand, the *peaks* of waves from some apertures are synchronized with the *troughs* of the other waves, everything cancels out and we say that “destructive interference” occurred at that point. We see a dark region on the screen. The dashed directions in the diagram represent the angles of diffraction at which constructive interference takes place. The “order” N is the way to describe which of the above directions is involved (N=0, N=1, N=2, …).

If on the other hand we imagine light as a stream of photon particles, we interpret the intensity of waves at any given place as telling us the probability of detecting a photon there. So photons are more likely to hit regions on the observation screen that are bright (that is why they are bright!). We can understand the diffraction process as the Uncertainty Principle applied to photons. The grating localizes photon position because they are forced to go through the narrow slits. This introduces uncertainty in the photon momentum and that results in the spreading out because momentum is mass x velocity and velocity includes the direction of motion.

To perform this experiment we need to send onto the grating a well-collimated coherent beam of light of a one wavelength. Laser light is distinguished from other common light sources because it is amplified, monochromatic, collimated, and coherent. Light is monochromatic if it consists of a single color, or equivalently, a single wavelength or frequency. Collimated means that the light produced is composed of parallel light wavefronts. Coherent light is composed of light waves that have a constant relative phase; at any given place, all the light passing through from the source has a maximum at the same time. In terms of photons, lasers produce photons of the same energy (by Planck’s formula $E = hf$ this implies monochromatic frequency f), travelling in the same direction (collimated), and with wavefunctions that are in-step (coherent).

<u>Procedure & Equipment</u>
2 x meter sticks, short ruler, diffraction grating & holder, laser flashlight.



1) Place two meter sticks on the table in an L-shape, with the metric scale up. Have one end of one stick be flush with the table edge (this is where the grating will go to make observation easier). These meter sticks form the sides of a right-angled triangle that can be used to calculate the angles of diffraction **θ**.
2) Position the grating (in its holder) at the table edge end of one meter stick, so that you are looking back through it at the corner of the L.
3) Place an opaque (not shiny) obstacle at the corner of the L and shine the laser light onto it so that a dot is reflected.

CAUTION!

Viewing laser light directly will burn the eye, causing permanent damage!

Only view the reflected laser light from an opaque surface!

You are responsible for the safety of other students in this lab too!

4) By the time the reflected light from the obstacle reaches the grating, its wavefronts are approximately parallel. Your eye is going to be the observation screen behind the grating. Place your eye on a level with the grating and look through it, back towards the dot reflection at the corner of the L. You are seeing the **N=0** image. Further to the right (or left) you should see another red dot. This is the first order diffraction image (**N = 1**). The higher orders N > 1 are probably too far out for you to see with this equipment.

.**Trouble Shooting**

- You may need to bring your eye closer to the grating
- Move your line of sight, not the grating; keep the grating facing the corner of the L.
- The grating may not be oriented correctly in its holder – take out and rotate by 90 ^{0}
- Remove any other light source in your line of sight

5) Record

y = distance from the grating to the reflected dot (N=0 image)

One partner should look through the grating and guide the other partner to the position on the perpendicular ruler where they see the N=1 image. The partners should then reverse roles and average their measurements for

x = distance between the N=0 and N=1 images

Analysis

- Calculate the N=1 angle of diffraction from trigonometry using

  $$\theta = \arctan(x/y)$$

  Arctan is the inverse of the tangent, also written as $\tan^{-1}$, and may be found on a calculator.

- The grating has 13400 apertures per inch and 1 inch = 2.54 cm. Use this calculate the distance d in meters between successive apertures.

- Hence calculate the wavelength λ of red laser light in meters using the diffraction formula for constructive interference

  $$N\lambda = d \sin\theta$$

- The de Broglie formula $p = h/\lambda$ (discussed in the next class) can be used to calculate the momentum p of one photon from the wavelength λ of its probability wave. Use Planck's constant $h = 6.64 \times 10^{-34}$ kg m^2 s^{-1} to calculate the momentum of red laser photons.

- If we regard the size of one aperture in the grating as the photon's sideways position uncertainty Δx and the sideways component of momentum $p \sin\theta$, introduced by the grating as the photons pass through, as its momentum uncertainty Δp, verify that Heisenberg's Uncertainty Principle is obeyed

  $$\Delta x \, \Delta p > h/(4\pi)$$