Introduction

For the first part of the Optics Lab, we used *geometric optics* to model light. The geometric model assumes light travels in straight lines between refracting or reflecting surfaces and can have an arbitrary *beam pattern*. When the beams get small in diameter, like for a laser, a limit is reached where the wave nature of light must be used. The Gaussian beam model is a very useful model, especially when lasers are involved. Interestingly, this model is used for highly directional microwaves and radio frequency radiation.

The Beam Pattern

A beam pattern is the *horizontal* dependence of the intensity of light. For example if you shine a laser beam on a wall and get close to it you will see something like *Figure 1*. Notice that the spot is brightest in the center and it is circularly symmetric. We need a function that describes this intensity pattern. A function we will find useful is a *Gaussian* profile for the electric field intensity is

$$E_s(r)=E_0\exp\left(-\frac{r^2}{w_0^2}\right)$$

where r is the radius from the origin, w_0 is the diameter at 1/e of the maximum amplitude, and E_0 is the electric field amplitude. Note that where $r=w_0$, $E_s(w_0)=E_0/e\approx 0.37\,E_0$

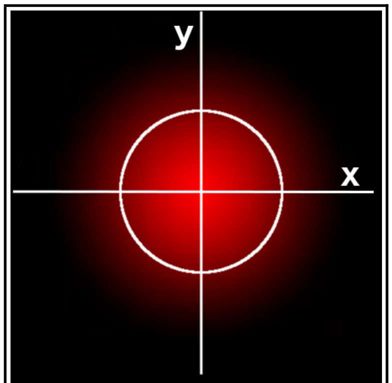

Figure 1: Close up of laser spot.The white circle shows the 1/e amplitude contour.

A propagating wave with a Gaussian profile is a solution to Maxwell's Equations, so this profile is fully consistent with the wave nature of light.

From ray optics you know that if you put a positive lens in collimated beam (and a laser beam is collimated) it focuses down to a point one focal length from the lens. How is this described using a Gaussian beam?

You can solve Maxwell's equations for a converging Gaussian beam. The result is that the beam diameter gets smaller and smaller, but instead of converging to a point, it reaches a minimum diameter at the focal point of the lens (called the *beam waist*), then starts diverging. So the basic picture from ray optics is still true, but the wave nature of light modifies the result. *Figure 2* show a section of a Gaussian beam as it goes through a focal point. The red curve shows the 1/e contour versus distance along the propagation direction.

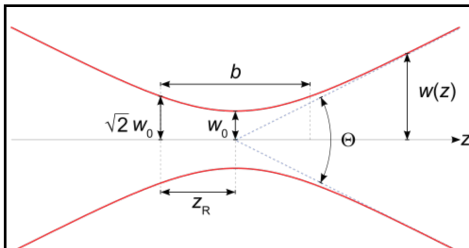

Figure 2: Gaussian beam width w(z) as a function of the distance z along the beam.The 1/e amplitude contour is plotted.

The dashed lines show the non-wave picture: the light would converge to a point in a cone, then diverge with the angle Θ being the convergence and divergence angle. When the wave nature of light is taken into account, you get the "smoothing" over a distance characterized by b and a minimum radius of w_0. The beam radius as a function of z is

$$w(z)=w_0\sqrt{1+\left(\frac{\lambda z}{\pi w_0^2}\right)^2}$$

where λ is the wavelength of light and *z* is defined as zero at the beam waist. It is remarkable that the whole profile is determined by only two parameters: the wavelength and the waist diameter. The *Rayleigh range* is defined by

$$z_R = \frac{\pi w_0^2}{\lambda}$$

At a distance $\pm z_R$ from the beam waist, the diameter of the beam is $\sqrt{2} w_0$ and $b = 2 z_R$. The last parameter of interest is the asymptotic angle. It can be derived as

$$\Theta = 2 \frac{dw}{dz} \approx \frac{2\lambda}{\pi w_0} \quad .$$

You should verify these relationships before going on.

Goal of Project

The goal of the project is to set up a computer & Arduino-controlled, precision translation stage and take beam profile data for a HeNe laser. Once the beam is measured, you will expand the beam, then focus it down to a waist. You will measure and characterize the beam waist and compare it to a Gaussian beam.

One extension is to the do same with the beam from a laser diode. You will compared it to the results for the HeNe laser.