AL-Mustaqbal University
College of Engineering
Department of Medical Instrumentation
Techniques Engineering
Zahraa Razaq & Huda Asaad
E-Mail: huda.asaad@uomus.edu.iq

EXP.NO: 2

Name of experiment: **Divergence of Laser Beam**

Purpose of experiment: 1. Find the divergence of the laser beam.

2. Find the wavelength of laser beam.

Apparatus: • Optical bench. • Optical rail. • He-Ne Laser. • Screen.

Theory: The light emitted by a laser is confined to a rather narrow cone; highly directional nature of a laser "Directionality "is the characteristic of laser light that causes it to travel in a single direction within a narrow cone of divergence But, perfectly parallel beams of directional light, cannot be produced. All light beams diverge as they move through space. But laser light is more highly collimated; it is more directional than the light from any source and thus less divergent (fig. 1).

But, as the beam propagates outward, it slowly diverges or fans out. Figure 1, greatly exaggerated, illustrates the way in which a beam of circular cross-section diverges. At the output aperture of the laser, the beam diameter is d. Its beam divergence angle is θ, usually expressed in milliradians. In traversing a distance ℓ. the beam diverges to a circle of diameter *d'*. Simple geometrical considerations indicate that for a small divergence angle, the diameter *d'* of the beam at a distance from the output aperture is approximated by Equation 1. In the past, some manufacturers have specified the "half-angle beam divergence" given as $\theta/2$ in Figure 1. The most common practice in recent years has been to specify the "full angle beam divergence”.

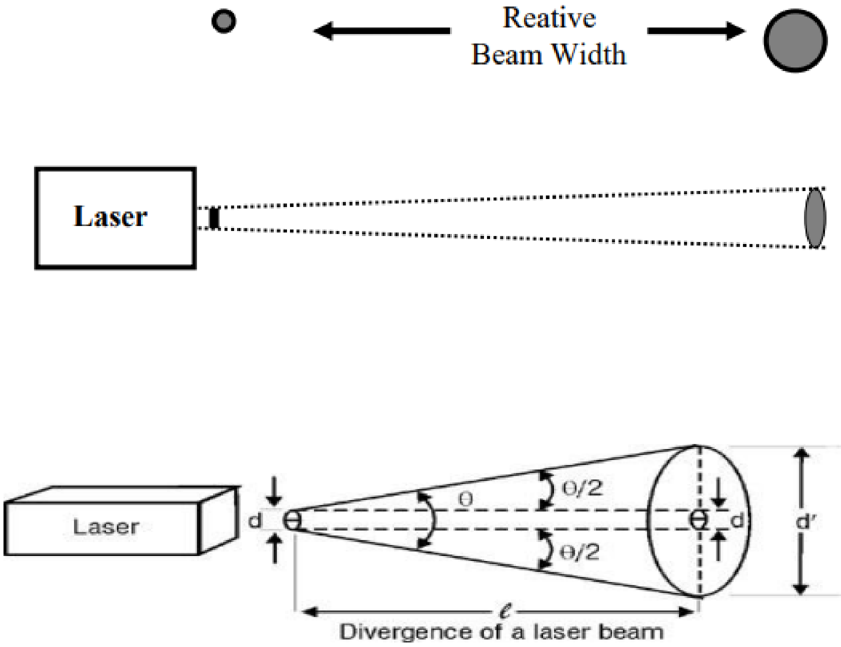

Figure (1): Divergence of the beam.

$$d' = \ell\theta + d \qquad (1)$$

Where:

ℓ : Distance from laser output aperture to measurement position.

θ : Full-angle beam divergence in radians.

d: Initial beam diameter.

d': Beam diameter at measurement position.

MEASURING BEAM DIVERGENCE

The divergence of a CW laser beam can be determined by measurement of the beam diameter at two points (Figure 2). The full angle beam divergence is given by Equation 2.

$$\theta \approx \frac{d_2 - d_1}{l_2 - l_1} \qquad (2)$$

Where:

d_1 = Beam diameter at point 1.

Zahraa Razaq &Huda Asaad
E-Mail: huda.asaad@uomus.edu.iq

d_2 = Beam diameter at point 2.
l_1 = Diameter from laser to point 1.
l_2 = Diameter from laser to point 2.
Equation 2 is valid for small θ, typical of most lasers.

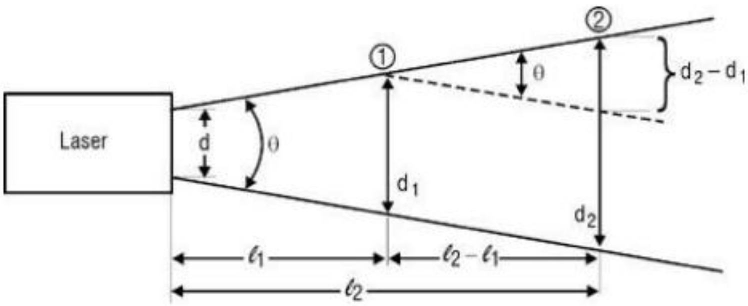

Figure (2): Measurement of beam divergence.

Figure 3 illustrates the optical cavity and beam profile of a typical gas laser. The laser beam diverges in the cavity as it strikes the output coupler, and would diverge even more outside the cavity if the second surface of the output coupler were flat. To prevent greater divergence, the second surface is curved slightly more than the first surface to form a positive lens that collimates the beam. The output coupler actually is a positive lens that has a focal length equal to the radius of curvature of its reflective surface.

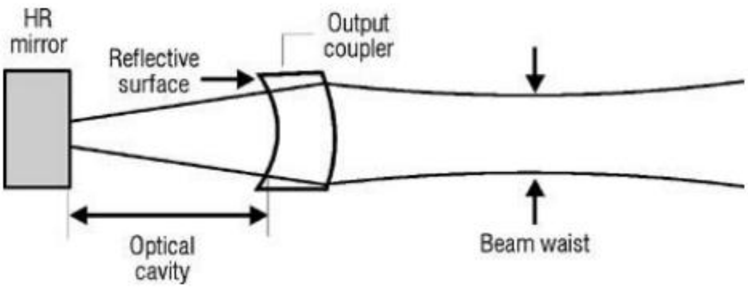

Figure (3): Collimation of a laser beam by the output coupler.

In most cases, this results in a slight convergence of the beam just past the output aperture. The beam passes through a minimum diameter, or "waist," and then diverges. This external beam waist serves as a "controlling aperture" which determines the beam divergence as the beam continues on past the beam waist.

Zahraa Razaq &Huda Asaad
E-Mail: huda.asaad@uomus.edu.iq

THE NEAR AND FAR FIELDS

The discussion of beam divergence accompanying Figure3 approximates the behavior of the beam near the laser only. The use of Equation 1 and 2 are valid only in the "for fills," at a certain distance from the laser.

$$Far\ field: \ell \geq 100\frac{d^2}{\lambda} \qquad (3)$$

Where:

ℓ: Distance from laser to observation position.

d: Diameter of output aperture.

λ: Wavelength of laser light.

The region closer to the laser is the "near field" and is defined by the condition given by Equation 4:

$$Near\ field: \ell \leq \frac{d^2}{\lambda} \qquad (4)$$

The beam divergence in the near field may differ considerably from that in the far field, as illustrated in Figure 3. Why the difference in divergence occurs is beyond the scope of this module. In the "gray area" between the near field, defined by Equation 4, and the far field, defined by Equation 3, one may use Equation 1 and 2 to obtain reasonable approximations of the laser beam divergence. They involve simple calculations and good "ballpark" results. The far-field beam divergence (full angle) of a laser is given by Equation 5. This equation is the "diffraction limited beam divergence" because it is the minimum divergence possible when light of wavelength λ is diffracted as it passes through an effective aperture of diameter d.

$$\theta = \frac{1.27\lambda}{d} \qquad (5)$$

It is well to point out here that the effective aperture "d" in Equation 5 is in truth equal to the diameter of the beam waist located somewhere in the cavity of the laser. That is always the case of the output coupler does not further reshape the output laser beam as it exits the laser. If the output coupler does as show in Figure 3, then the effective aperture "d" is the diameter of that beam waist formed by the output coupler located external to the laser beam, as shown in Figure 3. It is also well to point out that, for an ordinary light beam passing through a circular hole of diameter "d" (a light beam described as plane waves with a uniform intensity) the

Zahraa Razaq &Huda Asaad
E-Mail: huda.asaad@uomus.edu.iq

correct far-field beam divergence is given by $\theta = \frac{2.44\lambda}{d}$. But, for a TEM_{00} gaussian laser beam, the correct far-field beam divergence from a cavity is precisely as given in Equation 4. Do not confuse the two situations. They are distinctly different.

Procedure:

1. Arrange the components as figure below:

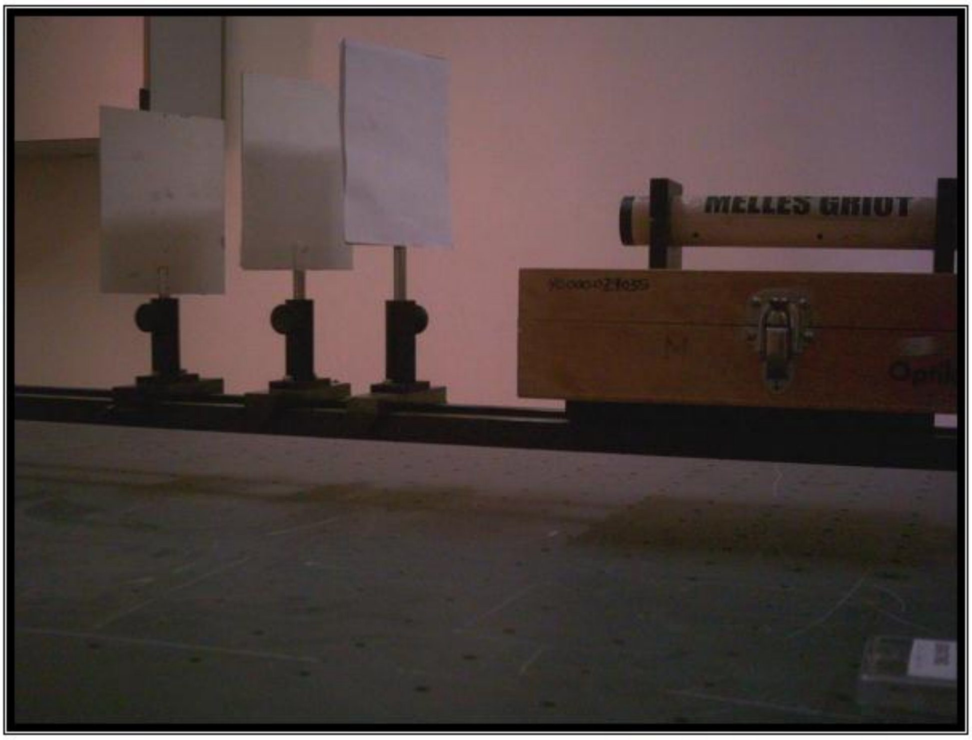

Figure (4): Experimental Photograph.

2. Put the screen at a distance (l) equal 10 cm from the laser.

3. Determine the diameter of the aperture of the He-Ne laser spot (d).

4. Increase the distance (l) from (10 to 100) cm and determine (d_m) at each 10 cm. Decrease the distance from (100 to 10) cm, determine d m at each 10cm.

5. Plot a curve for d_m as a function of l and find the slope. Find also the experimental value of the solid angle (θ) from equation (2).

6. Calculate the wave length of laser source from equation (4).

Zahraa Razaq &Huda Asaad
E-Mail: huda.asaad@uomus.edu.iq

l (cm)	d_m *(cm)*	d_m *(cm)*	d_m *(average)*
10 100			

Discussion:

1. What is the reason for laser beam divergence?

2. Define limited diffraction angle.

3. A laser beam has a diameter of 1.2 cm at a distance of 10 m from the laser and a diameter of 7.5 cm at a distance of 35 m. Determine the beam divergence angle.

4. A He-Ne laser beam has a diameter of 3.5 mm at a distance of 2 m from the laser. At 4 m, the beam has expanded to a diameter of 5.9 m, find divergence.