Generation of Higher Order Modes in an Open-Cavity Helium-Neon Laser

Izzy Bellehumeur[1], Kevin O'Shea [2] , Harold Metcalf [2]

[1]Middleton High School, Middleton, WI, 53562, USA

[2]Department of Physics and Astronomy, Stony Brook University, Stony Brook, NY, 11794, USA

Stony Brook University

Laser Cavities

A laser cavity is the space between two mirrors where light bounces back and forth. Inside, the gain medium causes excited atoms to emit light, adding to the intensity.
Mirrors reflect light repeatedly allowing light patterns to form.

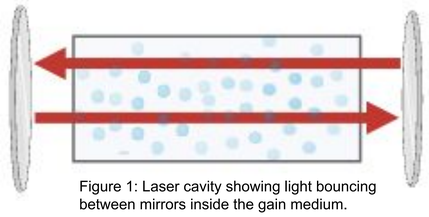

Figure 1: Laser cavity showing light bouncing between mirrors inside the gain medium.

Open-Cavity HeNe Laser

Unlike sealed cavity lasers, the open cavity uses an external mirror to adjust cavity length. This allows objects like hair or wire to be placed in the beam path, letting us study their effect on beam shape and Hermite-Gaussian modes.

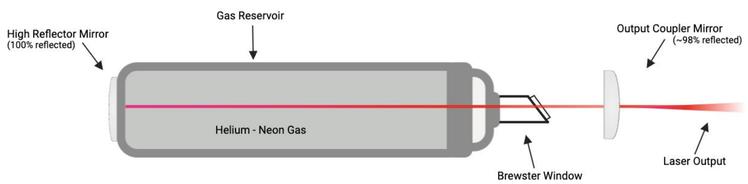

Figure 2: Schematic of the open-cavity HeNe laser setup

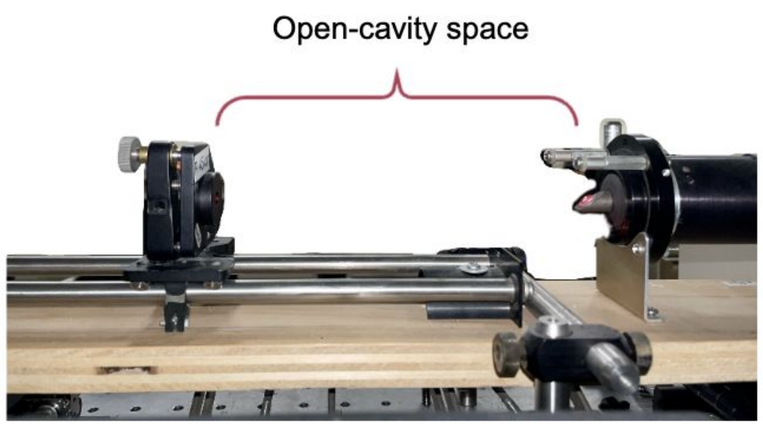

Figure 3: Open-cavity setup

Hermite-Gaussian Modes

Laser cavities support multiple transverse electromagnetic (TEM) modes, with Hermite-Gaussian modes being common in common cavities. These are labeled by indices (m,n) indicating the number of nodes in two orthogonal. The TEM_{00} forms a circular beam, while higher modes like TEM_{10} and TEM_{01} show alternating bright and dark regions

The Hermite-Gaussian modes are solutions to the paraxial wave equation:

$$\left(\frac{\partial^2}{\partial x^2}+\frac{\partial^2}{\partial y^2}+2ik\frac{\partial}{\partial z}\right)\tilde{E}(x,y,z)\cong 0$$

This equation applies when a laser beam mostly moves straight along the z-axis, as it does in a laser.

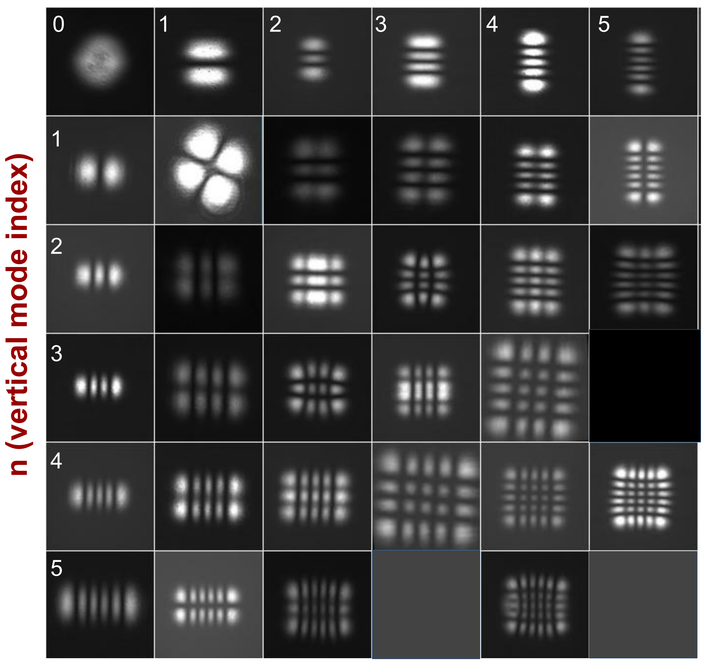

Fig 6: modes (0,0) through (5,4) and (4,5). (5,3) and (3,5) were not able to be generated

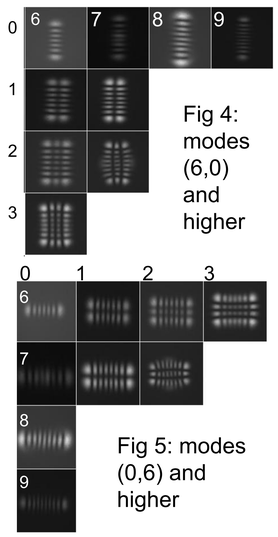

Fig 4: modes (6,0) and higher

Fig 5: modes (0,6) and higher

The observed modes match well with those predicted and previously published results [3, 4]. These clear (m,n) patterns were expected and validate the use of the open-cavity method for mode generation. However, I was unable to generate very high-order modes such as (7,4) and above, due to the limitations of the cavity.

Creation of HG Modes

To visualize the transverse modes I inserted a hair into the laser cavity. The obstruction introduces regions of zero intensity, known as nodes. Only modes with zero intensity at that region will remain visible.

Figure 4: Rotation mount with strand of hair. Was inserted into laser cavity to create HG modes

Why it matters

Cylindrical lenses convert Hermite-Gaussian modes into Laguerre-Gaussian (LG) beams, which are twisted light that carrying orbital angular momentum.

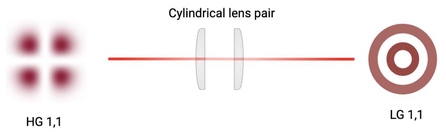

Figure 5: Conversion of HG beams to LG beams with cylindrical lenses

These LG beams work with optical tweezers to trap and rotate microscopic particles without contact, helping scientists study single cells and manipulate DNA with high precision.

Acknowledgments

Thank you to the Simons foundation for supporting this research and to the Laser Teaching Center for providing us with the opportunity and materials to carry this project out.

References

1. MxS. (2016). *Final summer talk* [PDF]. Stony Brook University Laser Teaching Center. https://www.stonybrook.edu/laser/_mxs/summer-2016/final-summer-talk.pdf
2. Oxford University. (n.d.). *HeNe laser mini project* [Lab report]. https://users.ox.ac.uk/~corp2485/labWork/HeNeLaserMiniProject.pdf
3. Hamsa. (2007). *Intel ISEF abstract* [PDF]. Stony Brook University Laser Teaching Center. https://www.stonybrook.edu/laser/_hamsa/papers/Intel07.pdf
4. Nick. (n.d.). *Laser project abstract* [Web page]. Stony Brook University Laser Teaching Center. https://www.stonybrook.edu/laser/_nick/abstract.html
5. Wikipedia contributors. (n.d.). *Gaussian beam – Hermite–Gaussian modes*. Wikipedia. Retrieved August 5, 2025, from https://en.wikipedia.org/wiki/Gaussian_beam#Hermite–Gaussian_modes
6. Wang, F., Li, H., Xue, Y., & Wang, J. (2019). Generation of very high-order high-purity Gaussian modes via spatial light modulation. *Optics Communications*, 453, 124–130. https://doi.org/10.1016/j.optcom.2019.02.036
7. Hofer, L. R., Ritsch-Marte, M., & Schwarz, L. (2020). Hermite–Gaussian mode detection via convolution neural networks. *Optics Express*, 28(11), 16506–16519. https://lucas-hofer.com/publication/hermite_gaussian/