Physics Lab
ETH zürich

D PHYS

Helium-neon laser

Abstract

In this experiment the students

- learn to operate a gas laser, specifically a helium-neon (HeNe) laser
- gain a basic understanding of laser cavity modes
- understand how the frequency spectrum of a laser can be measured with a spherical Fabry-Pérot interferometer
- Investigate multi-mode and single-mode laser operation

Introduction

The cavity modes in a laser are given by the solutions of the paraxial Helmholtz equation [1]:

$$\frac{\partial^2\psi}{\partial x^2}+\frac{\partial^2\psi}{\partial y^2}-2ik\frac{\partial\psi}{\partial z}=0 \tag{1}$$

with the wavenumber $k = 2\pi/\lambda$ and the wavelength λ. The fundamental solution to Eq. (1) is the so-called Gaussian beam

$$\psi(x,y,z)\propto \exp\left(-\frac{r^2(x,y)}{w(z)}\right) \tag{2}$$

where r is the distance from the optical axis, w the beam diameter, and z the position on the optical axis.

More complicated solutions to Eq. (1) are called higher order modes, shown in Fig. 1. They can be labeled by a pair of transversal mode numbers (m and n, or l and p).

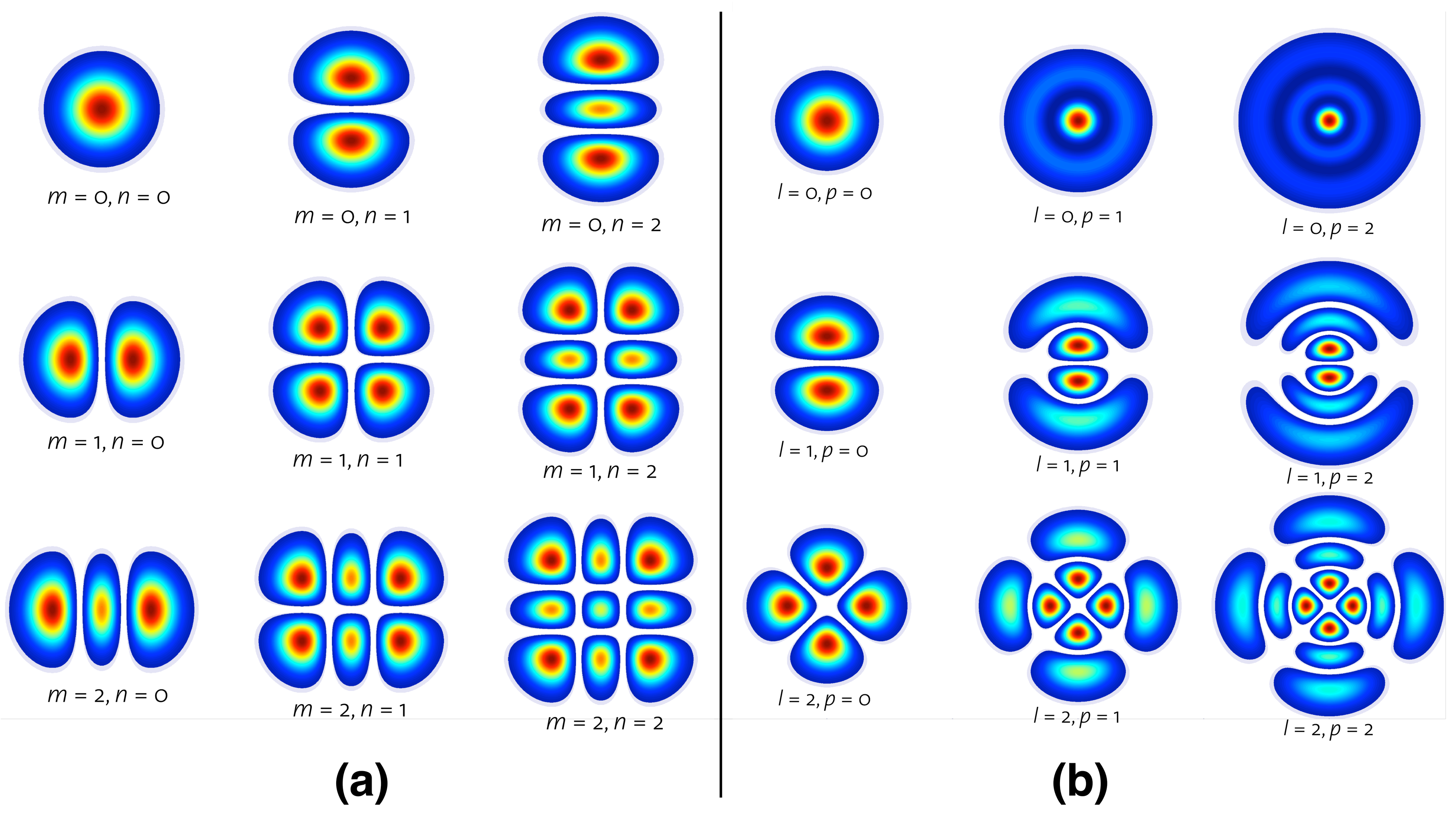


Fig. 1 – Propagation modes for **(a)** rectangular and **(b)** cylindrical geometry. The top left profile is in both cases a Gaussian mode.

In a cavity, light waves reflected back and forth between two mirrors can give rise to standing waves (Fig. 2). Their resonance frequencies depend on the transversal mode numbers (m and n) and on the length of the cavity.

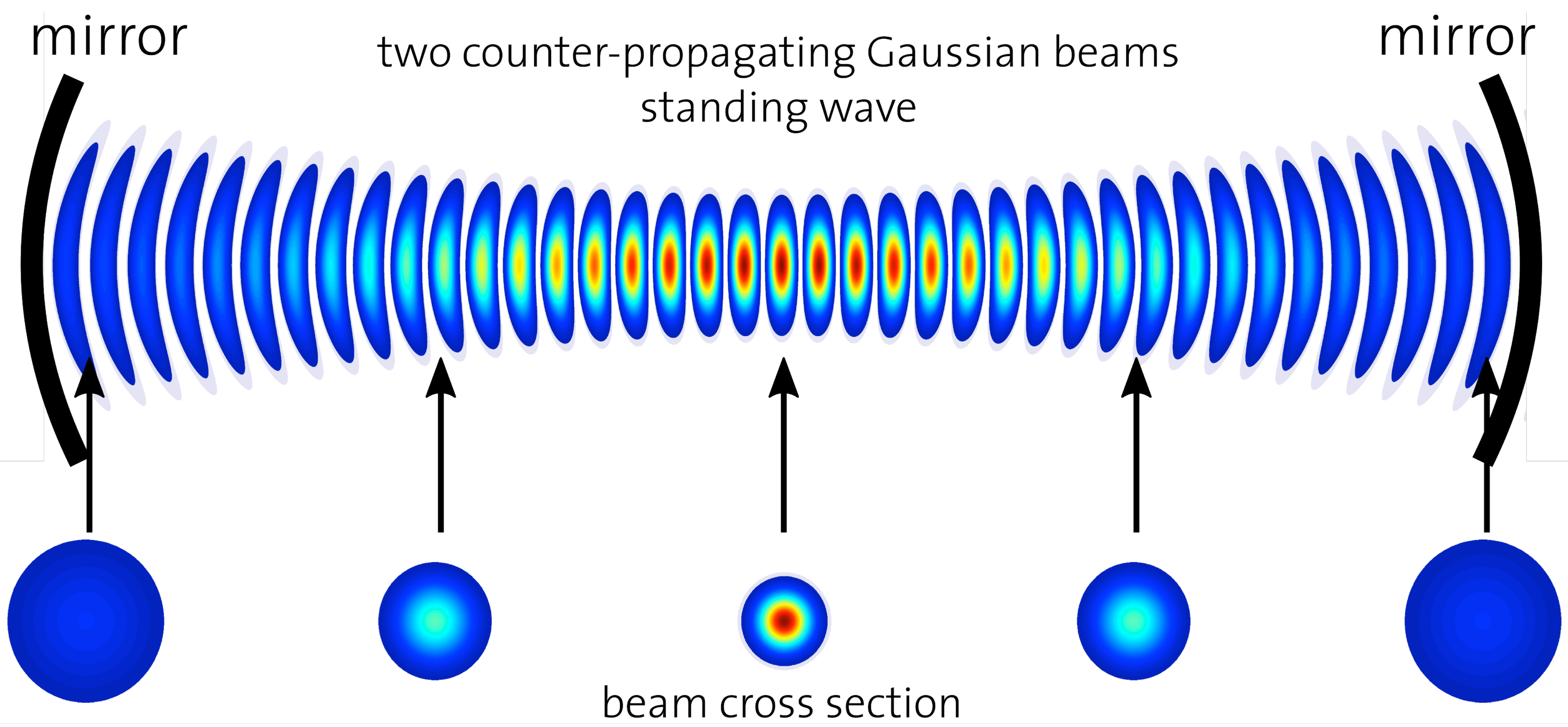


Fig. 2 – Two counter-propagating Gaussian beams forming a standing wave inside a cavity. The distance between the nodes is of the order of the wavelength, so that a 1-m long cavity would contain about 2 million nodes for a wavelength of 1 μm.

The frequencies of the different modes are given by [1]

$$\nu_{mnq}=\frac{c}{2d}\left[q+\frac{m+n+1}{\pi}\arccos\left(1-\frac{d}{\rho}\right)\right] \tag{3}$$

where m and n are the transversal mode numbers introduced in Fig. 1, q is the longitudinal mode number, d and ρ are the distance and radius of curvature of the mirrors, respectively. All modes are evenly spaced if the cavity is confocal (or degenerate) (Fig. 3).

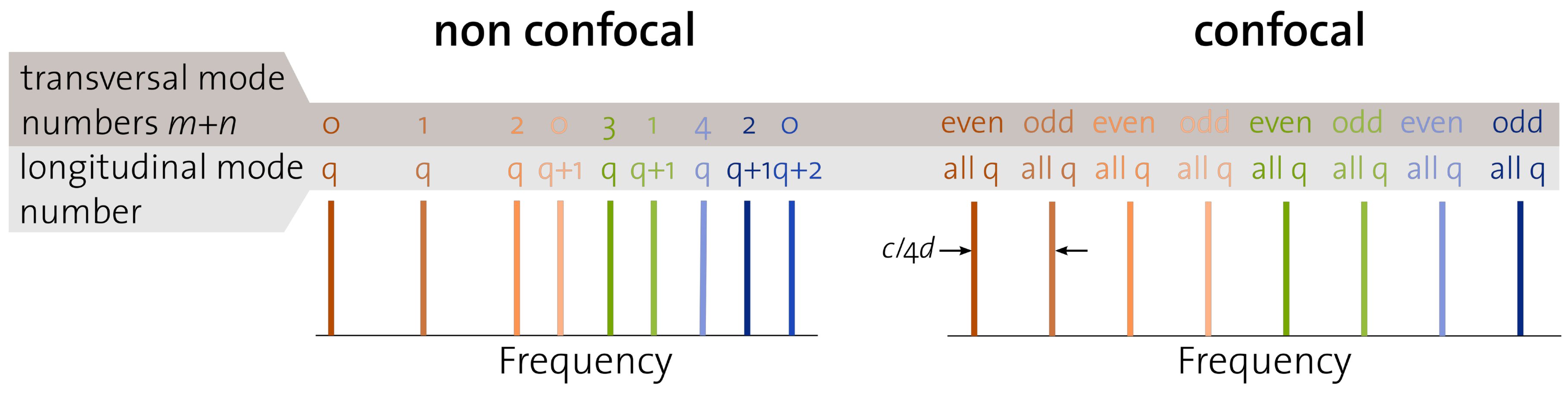


Fig. 3 – Resonance spectrum of a non-confocal and confocal cavity. In a confocal cavity (right), all modes are evenly spaced by $c/4d$.

Experimental Setup

The experimental setup is drawn schematically in Fig. 4. The laser beam produced by the HeNe laser is injected into a spherical Fabry-Pérot (SFP) interferometer. The SFP transmits light only when the laser frequency coincides with one of its mode frequencies, which can be shifted by altering the length of the SFP. The laser spectrum is recorded by connecting the photodiode to an oscilloscope.

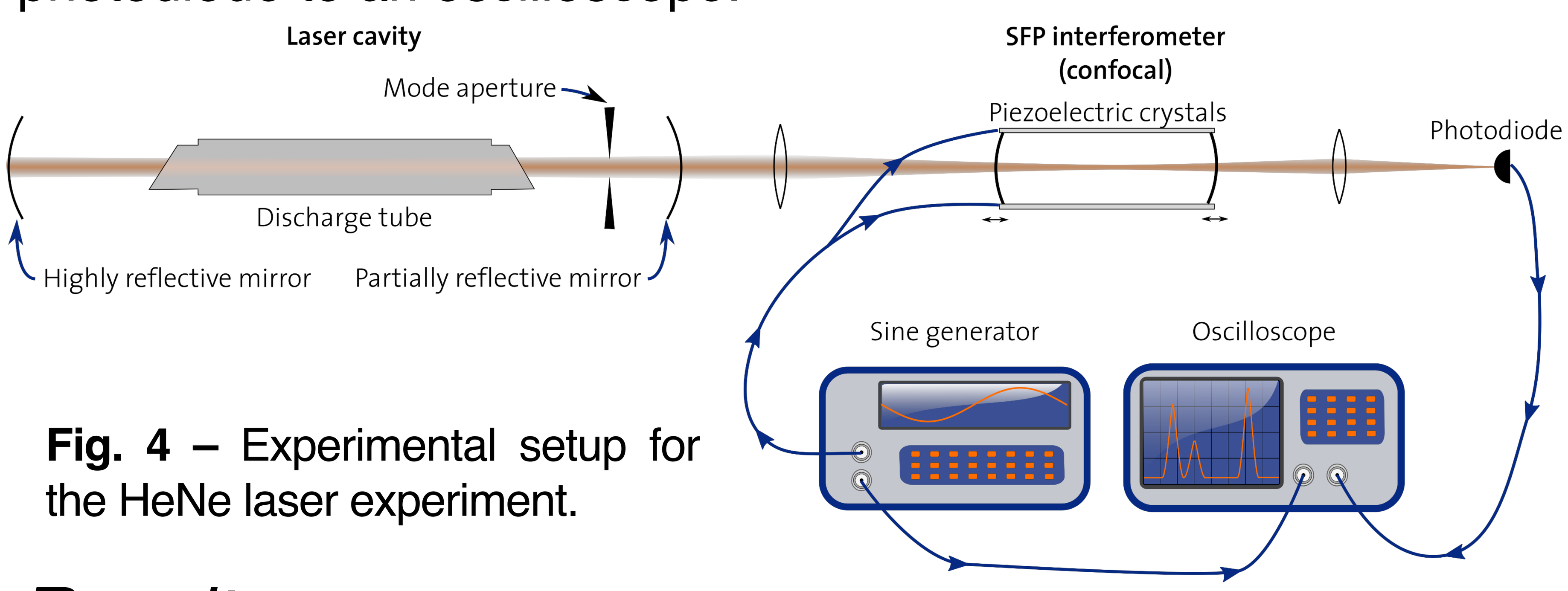
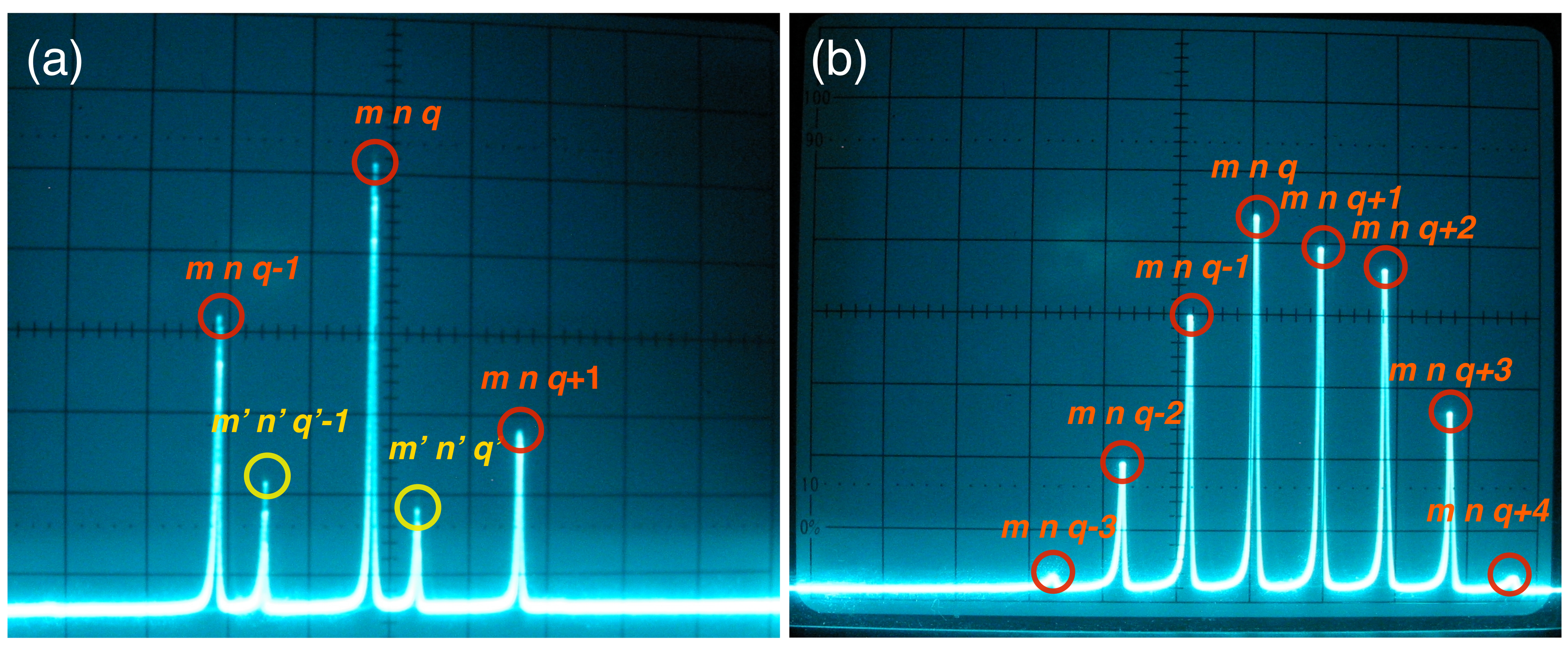


Fig. 4 – Experimental setup for the HeNe laser experiment.

Results

Once the laser mirrors are properly aligned and lasing is achieved, the laser will be multimode, that is, it will oscillate simultaneously on several modes. The mode spacing depends on whether several transversal modes are excited (different values of m, n, q, Fig. 5a), or several longitudinal modes (different values of q, but constant $m=n=0$, Fig. 5b). By inserting an aperture within the laser resonator, single-mode operation can be achieved (Fig. 5c).



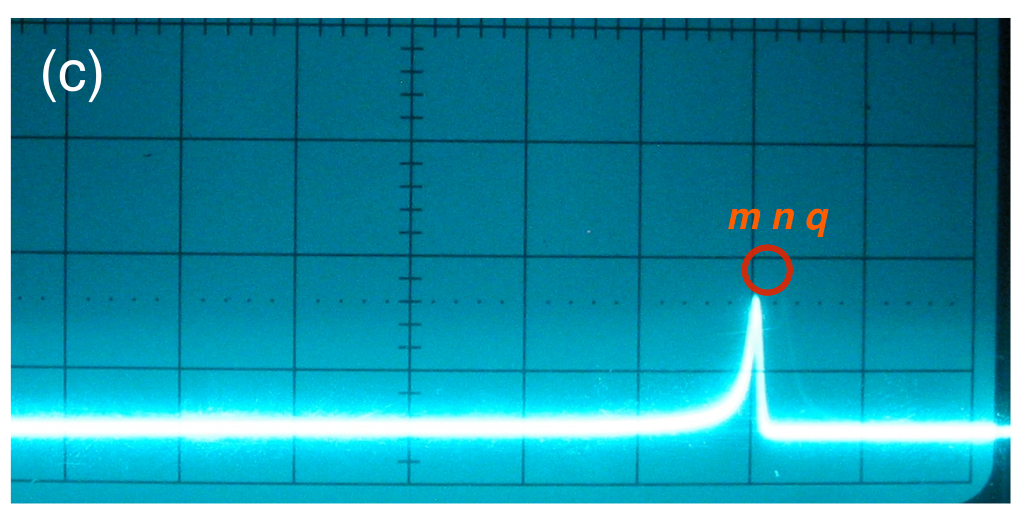


Fig. 5 – (a) Laser running on 3 longitudinal and 2 transversal modes. **(b)** Laser running on 8 longitudinal modes. **(c)** Single mode operation by placing an aperture within the laser cavity.

[1] Kogelnik and Li, *Laser Beams and Resonators*, Applied Optics **5**, 1550–1567 (1966)

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May 20, 2019