④ Longitudinal Modes of Operation

The physical dimensions of the Fabry-Perot resonator impose some additional constraints on the resulting beam characteristics.

While it is commonly believed that the 632.8 nm (for example) transition is a sharp peak, it is actually a Gaussian – bell shaped – curve. (Strictly speaking, it is something called a "Voigt distribution" which is a combination of Gaussian and Lorentzian – but that's for the advanced course. Gaussian is close enough for this discussion since the discrepancy only shows up way out in the tails of the curve.) In order for a linear or (Fabry-Perot) cavity to resonate strongly, a standing wave pattern must exist. This will only occur when an integral number of half wavelengths fit between the two mirrors. This restricts possible axial or longitudinal modes of oscillation to:

```
          L * 2          c * n
      W = ---------   or   F = ---------
            n            L * 2
```


```
              L * 2          c * n
          W = ---------   or   F = ---------
                n            L * 2
```


Where:

L is the distance between the mirrors (m).

W denotes the possible wavelengths of oscillation (m).

n is a large integer (order of 948,000 for W around 632.8 nm, L = .3 m).

F denotes the possible frequencies of oscillation (Hz).

c is the speed of light (approximately 300 million m/s).

The laser will not operate with just any wavelength – it must satisfy this equation. Therefore, the output will not usually be a single peak at 632.8 nm but a series of peaks around 632.8 nm spaced c/(2*L) Hz apart. Longer cavities result in closer mode spacing and a larger number of modes since the gain won't fall off as rapidly as the modes move away from the peak. For example, a cavity length of 150 mm results in a longitudinal mode spacing of about 1 GHz; L = 300 mm results in about 500 MHz. The strongest spectral lines in the output will be nearest the combined peak of the lasing medium and mirror reflectivity but many others will still be present. This is called multimode operation.

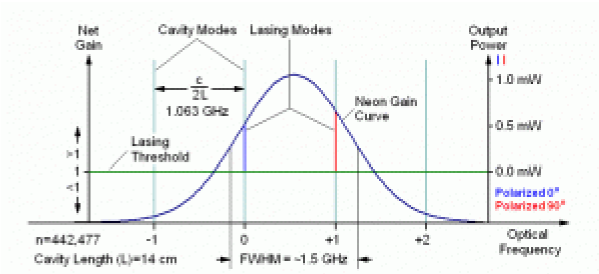
Think of the vibrating string of a violin or piano. Being fixed at both ends, it can only sustain oscillations where an integer number of cycles fits on the string. In the case of a string, n can equal 1 (fundamental) and 2, 3, 4, 5 (harmonics or overtones). Due to the tension and stiffness of the string, only small integer values for n are present with a significant amplitude. For a He-Ne laser, the distribution of the selected neon spectral line and shape of the reflectivity function of the mirrors with respect to wavelength determine which values of n are present and the effective gain of each one. And n will be much greater than 1!

For a typical HeNe laser tube, possible values of n will form a series of very large numbers like 948,161, 948,162, 948,163, 948,164,…. rather than 1, 2, 3, 4. A typical gain function showing the emission curve of the excited neon multiplied by the mode structure of the Fabry-Perot resonator and the reflectivity curve of the mirrors may look something like the following:

```
          |            632.8 nm
         I|              .
          |            | | |
          |          | | | | |
          |        | | | | | | |
```

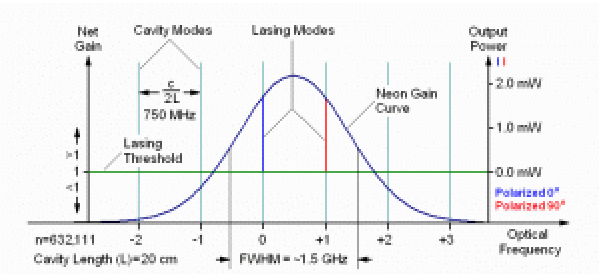

```
          |            632.8 nm
         I|              .
          |            | | |
          |          | | | | |
          |        | | | | | | |
   _______|______.__|__|__|__|__|__|__|__|__|__._______
      n=948,166  -5 -4 -3 -2 -1 +0 +1 +2 +3 +4 +5
```


Or, see the following for some slightly more aesthetically pleasing diagrams of the longitudinal modes of random polarized He-Ne lasers.



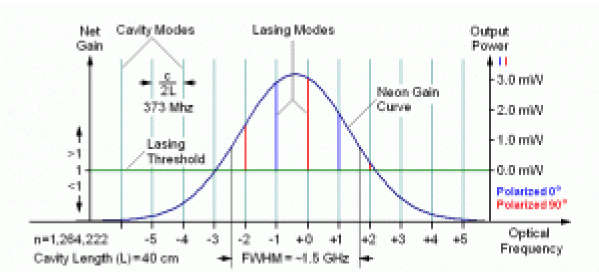
Longitudinal Modes of Typical Random Polarized 1 mW HeNe Laser

Longitudinal Modes of Typical Random Polarized 1 mW He-Ne Laser



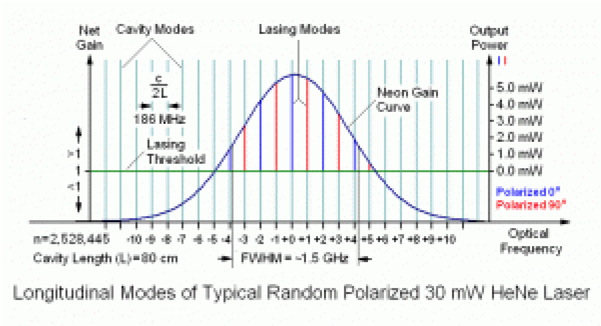
Longitudinal Modes of Typical Random Polarized 3 mW HeNe Laser

Longitudinal Modes of Typical Random Polarized 3 mW He-Ne Laser



Longitudinal Modes of Typical Random Polarized 8 mW HeNe Laser

Longitudinal Modes of Typical Random Polarized 8 mW He-Ne Laser



Longitudinal Modes of Typical Random Polarized 30 mW He-Ne Laser