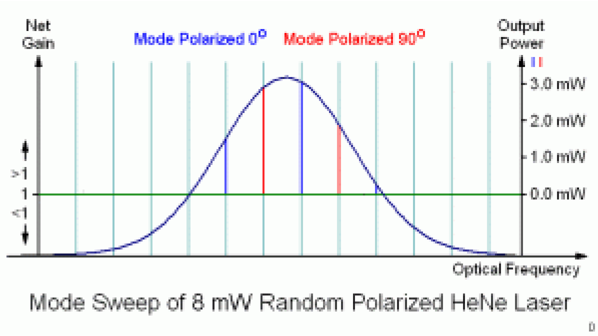
⑤ Mode Sweep

Since the mode locations are determined by the physical spacing of the mirrors, as the tube warms up and expands, these spectral line frequencies are going to drift downward (toward longer wavelengths). However, since the reflectivity of the mirrors as a function of wavelength is quite broad (for all practical purposes, a constant), new lines will fill in from above and the overall shape of the function doesn't change.

In the diagrams above, a single arbitrary mode position is shown, but for well behaved lasers, the lasing lines will move smoothly through the gain curve as the laser warms up. This is called by various names including "mode sweep" and "mode cycling". While present with most lasers, the effects are quite striking with low to medium power He-Ne lasers due to their relatively narrow neon gain bandwidth (which is only a small multiple of the longitudinal mode spacing in low to medium power He-Ne lasers), the rather fortuitous phenomenon that for red (633 nm) He-Ne lasers at least, adjacent longitudinal modes tend to be orthogonally polarized, and nearly ideal behaviour in other respects with the Physics mostly cooperating. (Murphy has seen the LASER DANGER signs and stays away!) Much more on all this below (except perhaps for Murphy).

In the nice diagram above of the 8 mW laser, there are 5 longitudinal cavity modes that see gain above the lasing threshold (the right-most just barely). These become lasing modes (red and blue) producing a total output power of somewhat over 8 mW in this specific example. For the 30 mW laser, there are twice as many lasing modes one half the distance apart, and each mode has more power. Interestingly, adjacent modes in a so-called "random polarized" red (632.8 nm) He-Ne laser are almost always orthogonally polarized, with the polarization axes fixed relative to the tube. (Here, one of them is arbitrarily referenced as 0 degrees, more on this later). As the distance between the mirrors is increased, the number of oscillating modes increases as well, though the actual power in each mode increases only slightly.



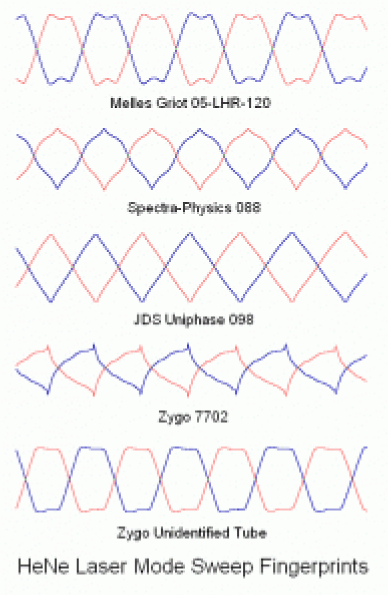
Mode Sweep of 8 mW Random Polarized He-Ne Laser

One complete cycle (red or blue) represents a change in cavity length of one wavelength (at 633 nm) and a change in optical frequency of 2 times the mode spacing of c/2L. The additional factor of 2 arises because the adjacent modes of the red (633 nm) HeNe are orthogonally polarized. This is not true with most other lasers and even HeNe lasers at other wavelengths. Note that while the profile of the mode sweep is affected by the neon gain curve, the period is NOT directly related to it, only c/2L.

However, note that as HeNe lasers get longer, mode competition results in greater and greater instability, so don't expect to see a nice orderly march with a Spectra-Physics 127 (39 inch cavity). In fact while the envelope of the modes will generally follow the gain curve, each mode will be jumping up and down in a quasi-chaotic dance! Instability may appear in the display of a Scanning Fabry-Perot Interferometer (SFPI) when viewing the longitudinal modes of a 633 nm HeNe with tubes rated at 7 to 10 mW. 5 mW lasers are usually quite clean while 35 mW lasers can be a real mess.

For very short HeNe tubes, the width of the gain curve may be similar to or even narrower than the spacing between modes. With those, the output power will become very low or go to zero during portions of the mode sweep. Very few HeNe lasers were produced with cavity lengths where this would be an issue since maximum output power would be very low. The only one I know of was the Spectra-Physics 119 stabilized laser with a 100 mm cavity length (mode spacing of 1.5 GHz). The very short cavity was required to provide special characteristics for this system.

In fact, it's often possible to go so far as to identify a specific manufacturer and even model of a HeNe laser tube based solely on the plots of its polarized mode sweep, providing a sort of "fingerprint" for lasers. For example, the type of tube installed in a Zygo or Teletrac/Axsys stabilized laser can be determined without opening the case!



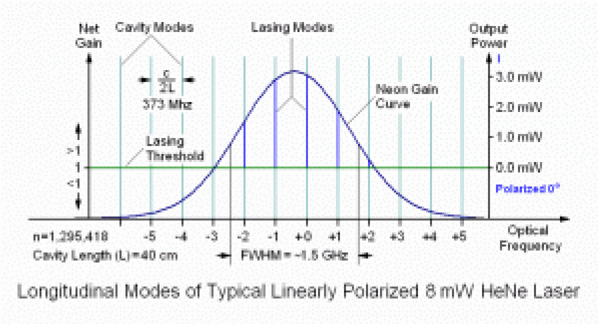
He-Ne Laser Mode Sweep Fingerprints

These tubes are all physically similar yet have dramatically different mode sweep plots. And, it's often possible to determine key information about the health of a laser tube by comparing its mode sweep with that of a new one. Over most of its life, the general shape will remain the same, but as the power declines, in addition to the total height of the plot decreasing, the amplitude of the variation (i.e., the AC component) relative to the total will increase. However, near end-of-life when power is way down and fewer modes are oscillating, the distinctions will tend to disappear.

For very long tubes like the 30 mW one in the example above where there are many longitudinal modes, the actual appearance of mode sweep may be rather chaotic as power shifts among the modes in a random dance. When I first observed this behaviour with a Melles Griot 05-LHP-928 (35 mW) He-Ne producing over 40 mW, I thought it might have been defective in some way despite the high power. But two other healthy samples behaved in a similar manner. So, don't expect to see nice well behaved marching modes for these high power lasers. There is often a hint of instability even in shorter tubes though it may be subtle – a few percent variation in the peak amplitudes not attributable to other causes like normal movement under the gain curve or power supply ripple.

The effects of mode sweep are more dramatic with short low pressure carbon dioxide (CO_2) lasers because for a given resonator length, the ratio of wavelengths (10,600 nm for CO_2 compared to 632.8 nm for He-Ne means that the longitudinal mode spacing is 16.7 times larger). In these cases, the laser output will turn on and off as it heats up and the distance between the mirrors increases due to thermal expansion. For this to happen in a 632.8 nm He-Ne would require the tube to be less than about 75 mm (3 inches) in length.

A linearly polarized He-Ne laser would have the same longitudinal mode spacing, but all the lasing modes would have the same polarization orientation (red or blue) as shown in the diagrams and animations, above.



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

So, someone with red/blue color-blindness (if there is such a thing) would see the diagrams for all them as being linearly polarized!