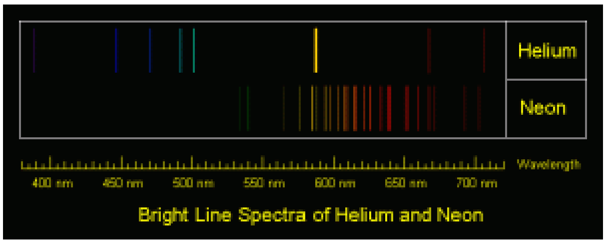
① Bright Line Spectra of Helium and Neon and the oscillating lines of HeNe laser

The term laser stands for "Light Amplification by Stimulated Emission of Radiation". However, lasers as most of us know them, are actually sources of light – oscillators rather than amplifiers. (Although laser amplifiers do exist in applications as diverse as fibre optic communications repeaters and multi-gigawatt laser arrays for inertial fusion research.) Of course, all oscillators – electronic, mechanical, or optical – are constructed by adding the proper kind of positive feedback to an amplifier.

All materials exhibit what is known as a bright line spectra when excited in some way. In the case of gases, this can be an electric current or (RF) radio frequency field. In the case of solids like ruby, a bright pulse of light from a xenon flash lamp can be used. The spectral lines are the result of spontaneous transitions of electrons in the material's atoms from higher to lower energy levels. A similar set of dark lines result in broad band light that is passed through the material due to the absorption of energy at specific wavelengths. Only a discrete set of energy levels and thus a discrete set of transitions are permitted based on quantum mechanical principles (well beyond the scope of this document, thankfully!). The entire science of spectroscopy is based on fact that every material has a unique spectral signature.

The HeNe laser depends on energy level transitions in the neon gas. In the case of neon, there are dozens if not hundreds of possible wavelength lines of light in this spectrum. Some of the stronger ones are near the 632.8 nm line of the common red HeNe laser – but this is not the strongest:

The strongest red line is 640.2 nm. There is one almost as strong at 633.4 nm. That's right, 633.4 nm and not 632.8 nm. The 632.8 nm one is quite weak in an ordinary neon spectrum, due to the high energy levels in the neon atom used to produce this line.



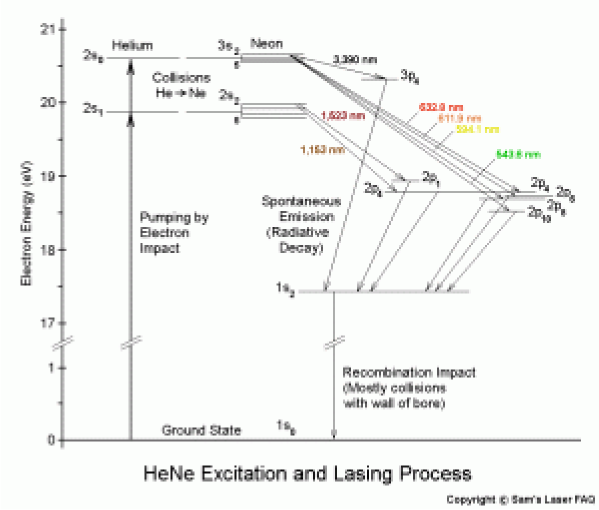
Bright Line Spectra of Helium and Neon

(The relative brightnesses of these don't appear to be accurate though at present.) More detailed spectra can be found at the: Laser Stars – Spectra of Gas Discharges Page. And there is a photo of an actual HeNe laser discharge spectra with very detailed annotation of most of the visible lines in: Skywise's Lasers and Optics Reference Section.

The comment about the output wavelength not being one of the stronger lines is valid for most lasers as if it were, that energy level would be depleted by spontaneous emission, which isn't what is wanted!

There are also many infra-red lines and some in the orange, yellow, and green regions of the spectrum as well.

The helium does not participate in the lasing (light emitting) process but is used to couple energy from the discharge to the neon through collisions with the neon atoms. This pumps up the neon to a higher energy state resulting in a population inversion meaning that more atoms in the higher energy state than the ground or equilibrium state.



Helium-Neon Excitation and Lasing Process

It turns out that the upper level of the transition that produces he 632.8 nm line (as well as the other visible He-Ne lasing lines) has an energy level that almost exactly matches the energy level of helium's lowest excited state. The vibrational coupling between these two states s highly efficient.

A DC electrical discharge or RF field excites He atoms to the 2s energy state.

Collisions efficiently transfer energy raising Ne atoms to the 3s2 energy state. Note the relatively high energy levels involved – over 20 eV for the upper energy states.

Stimulated emission (lasing) causes a drop to one of several Ne 2p states.

Radiative decay (spontaneous emission) drops Ne from the terminal lasing state to the 1s state.

Collisions with the tube wall drops Ne from the 1s state to the Ground state.

For 632.8 nm, one mirror will be highly reflective at 632.8 nm (typically 99.9 percent or better). This is the "High Reflector" or HR. The other mirror will have a typical reflectivity of 99 percent at 632.8 nm. This is the "Output Coupler" or OC from which the useful beam emerges. In order to suppress lasing at other wavelengths, the mirrors will generally be designed to have lower reflectivity there. (Though given the low gain of all the He-Ne lasing lines, especially the "other colour" lines, this isn't much of a problem at 632.8 nm.)

The rate at which (4) and (5) can take place ultimately limits the power of a He-Ne laser and explains why increasing the excitation (1) actually reduces power above some optimum level.

The gas mixture must be mostly helium (typically 5:1 to 10:1, He:Ne), so that helium atoms can be excited. The excited helium atoms collide with neon atoms, exciting some of them to the state from which they can radiate at 632.8 nm. Without helium, the neon atoms would be excited mostly to lower excited states responsible for non-laser lines. And the gas mixture has to be super pure as any contamination results in excitation of rogue atoms (like H, O, and N) to lower energy states where all that will happen is that they will glow like a poorly made neon sign.

A neon laser with no helium can be constructed but it is much more difficult and the output power will be much lower without this means of energy coupling. Therefore, a He-Ne laser that has lost enough of its helium (e.g., due to diffusion through the seals or glass) will most likely not lase at all since the pumping efficiency will be too low.

However, pure neon will lase superradiantly in a narrow tube (e.g., 40 cm long x 1 mm ID) in the orange (611.9 nm) and yellow (594.1 nm) with orange being the strongest. Superradiant means that no mirrors are used although the addition of a Fabry-Perot cavity (e.g., mirrors!) does improve the lateral coherence and output power.

This from a paper entitled: “Super-Radiant Yellow and Orange Laser Transitions in Pure Neon” by H. G. Heard and J. Peterson, Proceedings of the IEEE, Oct. 1964, vol. #52, page #1258. The authors used a pulsed high voltage power supply for excitation (they didn’t attempt to operate the system in CW mode but speculate that it should be possible).