Helium Neon Laser

Principle

The difference between spontaneous and stimulated emission of light is demonstrated. The beam propagation within the resonator cavity of a He-Ne laser and its divergence are determined and the relative output power of the laser is measured as a function of the tube's position inside the resonator and of the tube current.

There are four main parts to this experiment:

1. Set up the He-Ne laser. Adjust the resonator mirrors by use of the pilot laser. (left mirror: VIS, HR, plane; right mirror: VIS, HR, R = 1000 mm)
2. Measure the output power as a function of mirror spacing.
3. Measure the integral relative output power as a function of the laser tube's position within the hemispherical resonator.
4. Measure the beam diameter within the hemispherical resonator right and left of the laser tube.
5. Measure the integral relative output power as a function of the tube current.

Fig. 1: Experimental set-up of He-Ne laser system.

NOTE: Do not touch any of the optical surfaces. Even a piece of dust can be sufficient to stop the laser operating. A fingerprint will be fatal and VERY difficult to clean.

Theory

The He-Ne laser was the first continuous working laser and was invented by Javan *et al*. in 1961. Their work was the result of careful spectroscopic studies of inert gases which meant that the energy level diagrams and lifetimes for the different levels in these gases were well known.
Fig. 2 shows the reduced energy-level diagram for helium and neon. Only those levels important in the discussion of the excitation and laser processes at a wavelength of 632 nm are indicated. The left side of the representation shows the lower levels of the Helium atoms. Observe how the energy scale is interrupted and that there is a larger

difference in energy in the recombination process than is evident in the diagram. A characteristic of helium is that its first states to be excited, 2^1S_1 and 2^1S_0 are metastable, i.e. optical transitions to the ground state 1^1S_0 are not allowed, because this would violate the selection rules for optical transitions. Therefore by passing an electric current through the gas electron collisions can populate the 2^1S_0 level which is then long lived. Following an collision between an electron and the helium atom the helium atom, now in an excited state, can collide with a neon atom and transfer its energy.

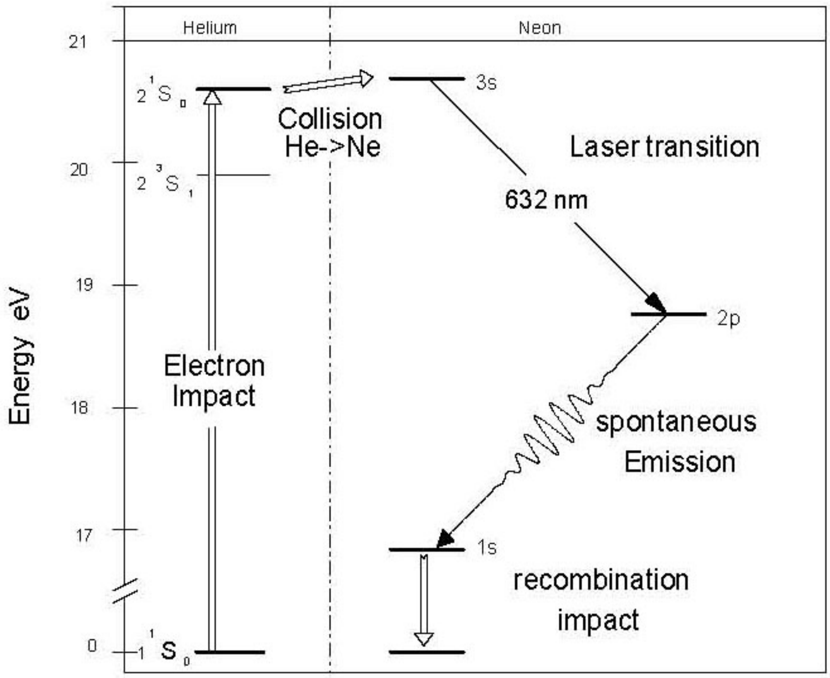

Figure 2: Excitation and laser process for the visible laser emission.

If we look at figure 2 we can see that the 2^1S_0 level is slightly below the 3s level of neon. However, the additional thermal energy kT is sufficient to overcome this gap. The lifetime of the s-states of the Neon are approximately 10 times longer than those of the p-states. Therefore an immediate population inversion between the 3s and the 2p levels will be generated as the 2p level is emptied due to spontaneous emission into the 1s level. After this the Neon atoms reach their ground state again, primarily through collisions with the tube wall (capillary), since an optical transition is not allowed. This relaxation process is the bottle neck in the laser cycle as neon atoms in the 1s state cannot be excited by a collision with a helium atom. It is therefore advisable to choose a capillary diameter that is as small as possible so as to help encourage collisions to get the neon atoms back into the ground state so that they can undergo further excitation. However, reducing the capillary diameter causes the laser to suffer more optical losses so modern He-Ne lasers need to work at an optimum under these contradictory conditions. This is the main reason for the comparatively low output power of He-Ne lasers compared with other available lasers.

Part 1 Set up the He-Ne laser

The general experimental set-up is shown in figure 1. When the He-Ne tube is switched on a pink glow can be seen to come from the gas in the capillary tube. This is the spontaneous emission from the excited gas molecules. To obtain lasing,

stimulated emission, from this gas it is necessary to form a resonator cavity with two parallel mirrors either side of the tube so that light can pass repeatedly through the tube being amplified on each pass.
The design of the optical resonator mirrors depends on the gain required and the required beam quality. It also depends on the type of gain material used, in this case excited neon atoms. The objective is to achieve the highest possible beam output in the basic Gaussian mode (TEM_{00}). Generally speaking these are two contradictory requirements since a high power output requires the use of a large volume of active material, whereas the fundamental mode is restricted to its own volume. For this reason a hemispherical resonator is used for He-Ne lasers where one of the mirrors is flat and the other has a concave surface. This arrangement has the additional advantage that it is easier to align the mirrors to produce lasing. This is the arrangement that is used in this laser experiment.

Alignment

Place the pilot laser onto the rail on the far right and fix the clamps. The pilot laser is prealigned to the optical axis of the set-up and forms the optical axis of the main laser. Mount the two diaphragms on to the track with the white sides facing each other. The first should be mounted in front of the laser aperture, the second should be mounted at the far end of the track. Switch on the pilot laser, the beam should be visible as a spot centered around the hole of the diaphragm. If your beam is not centered, this indicates the laser is not properly aligned down the optical track. **Do not make adjustments to the tube alignment on your own it is very easy to stop the laser from ever working. Ask a demonstrator.**

Mount the high reflectivity flat mirror (HR flat/flat) onto the left hand side of the rail, replacing the diaphragm. Make sure that the mirror mount is as far to the left as it can go (The mirror itself will be about level with the 5cm mark on the optical rail). Using the fine adjustment knobs on the back of the mirror, align the laser mirror such that the reflected beam is exactly centred on the diaphragm and enters the tube of the pilot laser onto the rail as shown in figure 2. Observe the back-reflected beam on the aperture of the diaphragm near the pilot laser. If this mirror is not accurately aligned it will be difficult (or impossible) to get the laser operating.

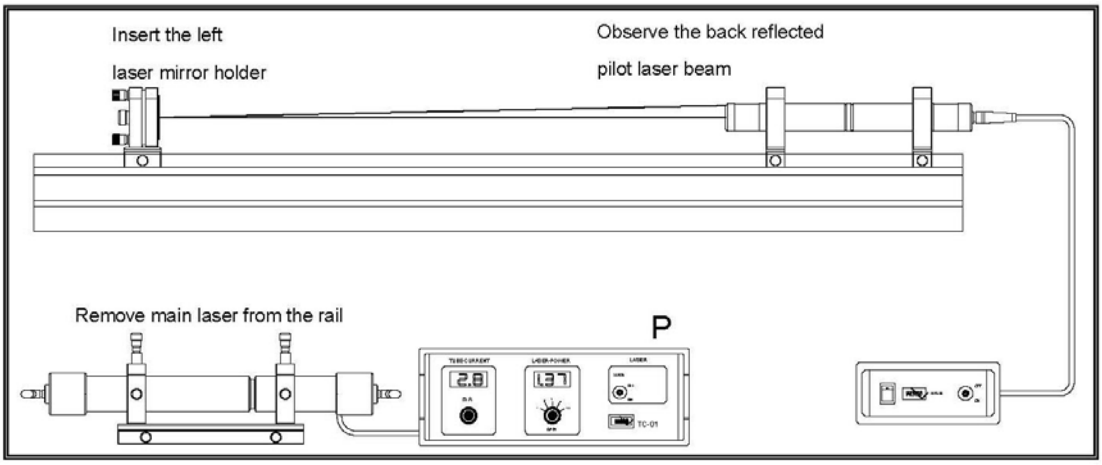

Figure 2. Alignment of the flat high reflectivity mirror.

In the next step the second laser mirror holder, with the high reflectivity mirror with a radius of curvature of 100 cm, is placed on the rail so that there is a spacing between the mirrors of ~70cm. Adjust the concave mirror so that the pilot beam is again

reflected back and is centred on the hole. This alignment is a more difficult as the reflecting surface is diverging the beam so the spot appears larger and less well defined.
Switch off the pilot laser and insert the main laser tube between the two mirrors, figure 3. The He-Ne tube should also be properly aligned on the rail so that the pilot laser beam passes the capillary of the He-Ne tube without any distortions.
Position the tube close to the plane mirror so that the left hand edge of the tube is ~1 cm from the plane mirror. Switch on the main laser tube power supply and set the tube current to 6mA. If you are very lucky the laser will start to oscillate immediately. However, it is more likely that you will need to make a small adjustment to the concave mirror to obtain lasing. If you have done the first part correctly only a small adjustment will be needed. If you make large adjustments and still cannot obtain lasing, you may need to remove the He-Ne tube and realign the mirrors. If this is the case always start from the alignment of the plane mirror. Once the laser is working replace the right hand diaphragm with the photodiode (make sure the laser is hitting the active area of the photodiode) and set the multimeter to measure microamps. The intensity of the laser is given by the current from this photodiode. Make small adjustments to each mirror in order to maximise the laser intensity. Ask the demonstrators for help if you cannot get the laser to operate.
Note that for a practical laser one mirror is a high reflector (99.9%) and the other is an output coupler with a reflectance of ~97%. For safety reasons both of the mirrors in this arrangement are high reflectors so the output power is kept very low. If the current reading after set up is <20µA ask a demonstrator to clean the laser optics.

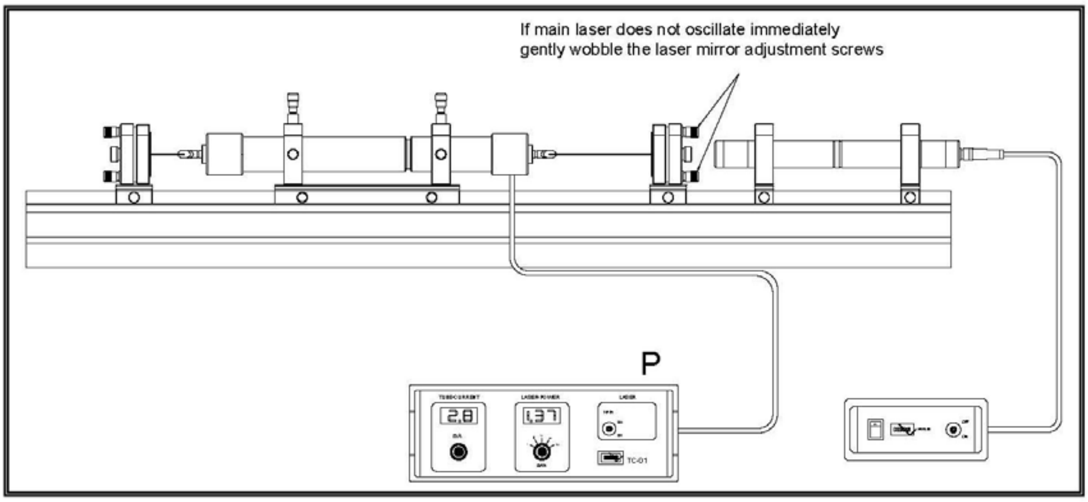

Figure 3. Final set up of the laser

Part 2 Measurement of the output power as a function of the mirror spacing
For this measurement you will measure the intensity of the laser whilst the position of the spherical mirror (R = 100 cm) is changed up to the stability limit (i.e. a mirror spacing of 100cm). The mirror can be shifted by slightly loosening the fixing screw on the base of the mirror adjustment support. Be careful that the laser does not stop working due to the shift. The adjustment support is fixed into the new position and the mirror is adjusted to get the maximum intensity. Start with the spherical mirror position so that the mirror spacing is ~45cm and record the output power as the laser is moved in 5cm steps. You should notice that at a spacing of ~95 cm there is a large

drop in the output power. Record the output power in 1cm steps beyond this point. Plot the intensity as a function of mirror spacing.
The peak in the output power at a spacing of ~85cm is due to the beam being focused into the laser tube so that a maximum amount of the gain medium is being utilised. You will see that the output power drops rapidly as the mirror spacing approaches the radius of curvature of the spherical mirror and the laser becomes very unstable and difficult to get operating. This is because the losses are rapidly becoming bigger than the gain and a stability limit is reached.

Part 3 Measure the integral relative output power as a function of the laser tube's position within the hemispherical resonator.
Move the spherical mirror so that the mirror spacing is 85cm and adjust the mirror to get the maximum output power. You should now measure the output power as a function of the position of the tube within the cavity. Move the tube to the right in 5cm steps (adjusting the spherical mirror to get the maximum output at each step) until the laser stops operating. Depending on how well aligned the laser is you should be able to move the tube by ~30 cm. Plot the intensity as a function of tube position.

Part 4 Measure the beam diameter within the hemispherical resonator.
Move the tube back to the optimal position (<1cm between laser tube and flat mirror) and ensure that the spherical mirror is at a mirror spacing of ~85cm. You should now measure the beam diameter at various points in the cavity. Make one measurement to the left of the tube and then take readings every 5cm to the right hand side.
To measure the beam diameter set the vernier callipers to a spacing of 1.5 mm. Move these back and forth through the beam path and see if the laser can be seen through the gap between the blades. If it can be seen reduce the spacing and repeat. The diameter of the beam is the minimum spacing where it was possible to keep the laser operating. Plot the beam diameter as a function of distance within the cavity.
Change the mirror spacing to 95 cm and repeat the measurements. How do you think these results help to explain what you observed in part 2.

Part 5 Measure the integral relative output power as a function of the tube current.
Move the tube back to the optimal position (<1cm between laser tube and flat mirror) and ensure that the spherical mirror is at a mirror spacing of ~85cm. Measure the output power as a function of the tube current, from the minimum to maximum values in 0.2mA steps. You should see that over a certain range the output power increases roughly linearly with tube current as more neon atoms are being forced into an excited state. However, as the tube current is increased further this effect saturates and it is even possible to see the output decrease. This occurs because the increased electron current in the tube causes excited neon atoms in the 3s state to be removed by further electron collisions.