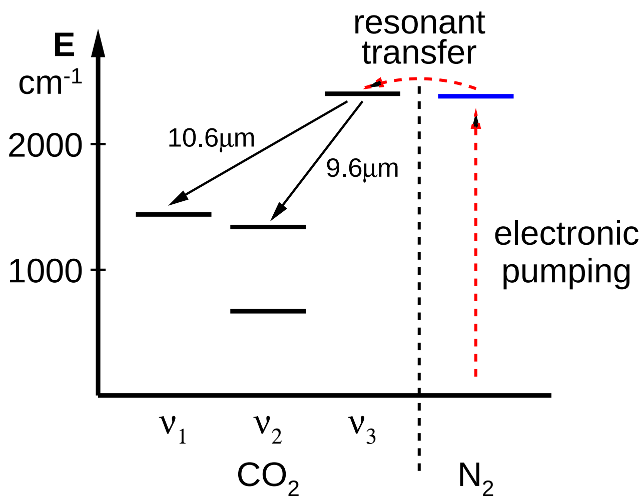
5 The CO_2 laser

The CO_2 laser works in the mid-IR range, 9–11 μm, on ca. 100 vibration–rotation transitions. In its classical version it operates at a pressure of 10–20mbar with a mixture of CO_2:N_2:He $\simeq$ 15%:15%:70%. The laser is pumped with current discharge, through a tube of 1–2m, requiring voltages of 10–20kV and a current of 10–20mA. Glass is opaque at 10μm so transmissive optics are made of NaCl, ZnSe, Ge or other IR materials.



The vibration level structure of CO_2 and N_2 is shown in the figure. The ν_1 mode in CO_2 is the symmetric stretch vibration (the C atom stationary), the ν_2 mode is the bending vibration of the otherwise linear molecule and the ν_3 mode is the asymmetric stretch vibration.

The N_2 molecule provides an effective pump channel with near resonance with the upper laser level. The energy difference is only 18 cm^{-1} compared to kT=208 cm^{-1} at $T = 300$ K. Helium acts as a cooling medium and speeds up the depopulation of the lower levels.

Each of the vibration levels is split into rotation levels marked with a rotation quantum number J. The rotational energy is given with

$$E_{rot} = BJ(J+1) \tag{1}$$

The energy constant $B \simeq 0.387\text{cm}^{-1}$ is inversely proportional to the moment of inertia of the molecule. The J levels communicate fast with each other with a lifetime of only a few nanoseconds, whereas the lifetime of the vibration channels is tens of microseconds. We can therefore assume $T_{rot} = T_{transl}$. The rotational population distribution is given with $N(J) = N_{vibr}\, f_J$, where

$$f(J) = [(2J+1)\exp(-BJ(J+1)/kT)]/Z_{rot} \tag{2}$$

Z_{rot} is the partition function for the rotation levels.

Transitions are governed by the selection rules $\Delta J = 0, \pm 1$. Transitions with $\Delta J = +1$ ($J_{lower} - J_{upper}$) are called P–lines, lines with $\Delta J = -1$ R–lines and lines with $\Delta J = 0$ Q–lines. The CO_2 laser has only P– and R–lines since for symmetry reasons the upper laser level has only odd J–values and the lower levels only even J–values. The spectral lines are arranged in bands Where the R–bands have higher frequency than the P–bands. There is a pair of bands for each of the lower vibration levels. At temperatures relevant to CO_2 laser discharge f_J peaks around $J = 20$ and in each band lasing can be achieved at 20–25 lines. The total number of lines is thus 80–100 all in the range of 9–11μm.

Line separation is of the order 50 GHz while linewidths are $\Delta\nu_D = 30$ MHz and $\Delta\nu_L = 30$ MHz. Saturation intensity is of the order 100 W/cm^2 which makes the CO_2 laser a powerful beast. The saturation intensity can be scaled up with pressure as p^2.