**Include:**

* Goal of this chapter
* How to get concentration from light, and relation to absorbance
* How the light travels
* Sources of noise still left (cannot defend the workings and elimination of other noise sources)
* (Link to appendix for list of components) not necessary if not meant to be reproducible
* Wavenumber range and other limitations

**(Goal)**

Measurements on the gas are performed with a spectroscopy setup using a quantum cascade laser. The various components and conditions of the measurement setup that influence the determination of the gas compounds and concentrations are explored. In order to understand how these components influence the eventual concentration, the path of light through the components is described starting from the quantum cascade laser (QCL) and ending at the CCD camera. For a more in depth analysis and reproducibility of the setup, refer to A. Reyes Reyes[REF].

**(concentration from light)**

In order to obtain information on the gas through spectroscopy, the interaction between light and matter needs to be established. The relation of the concentrations of the compounds in the gas to the light passing through is given by the Beer-Lambert law:

\begin{equation}  
I\_o (\lambda,C)= I\_i10^{-A(\lambda,C)

\end{equation}

with \begin{equation}

A(lambda,C) = \sum\_{c\_mol \in C,\epsilon\_mol(\lambda) \in \Epsilon(\lambda)} \epsilon\_mol(\lambda)\*c\_mol\*l$

\end{equation}

where $C$ and $\Epsilon(\lambda)$ denote the set of all concentrations and the set of all molar absorptivities respectively of the molecules in the gas.

The Beer-Lambert law states a relation between light with intensity $I\_i$ entering a gas, its absorbance $A(\lambda)$ by the gas, and its intensity $I\_o$ as it exits the gas. The absorbance is a function of the interaction length $l$ of the light with the gas, and the concentration $c\_mol$ and the molar absorptivity $\epsilon(\lambda)$ of the different molecules in the gas. The Beer-Lambert law shows that in the setup the interaction length and the intensity of the light going in and coming out of the gas must be measured.

**(travel path of light)**

To find the concentration of compounds within a gas the following spectroscopy setup is used:

[Picture of setup and diagram of setup (Zhe’s diagram p.20 of report)]

[figure a: Picture of the quantum cascade laser spectroscopy setup as used for measuring.

Figure b: Diagram of the spectroscopy setup.]

Begin{comment}

*The gain medium of the laser consists of alternating layers of semiconductor material which have different band gaps. The thickness of the layers is constructed such that the valence band of one layer coincides with the conduction band of the next layer. By virtue of the electrons being able to travel from the conduction band of one material to the valence band of the next layer, a voltage over the medium results in the QCL emitting light of different wavenumbers simultaneously.*

End{comment}

By way of its design the QCL emits different wavenumbers of light simultaneously. The CCD cameras used detects the intensity of the light without differentiating between the various wavenumbers. Since intensity per wavenumber is a necessity, a diffraction grating mounted on a piëzo is used to select a single wavenumber. The wavenumber allowed depends on the effective spacing of the grating, which is determined by the actual spacing and the incident angle of the light on the grating. The incident angle is controlled by applying a voltage over the piëzo. Two QCL’s are arranged such that together they can scan over the wavenumber range of 832 $cm^{-1}$ to 1263 $cm^{-1}$. The next chapter [REF] shows the measured signal and its noise, most of which can be assigned to the hysteresis occurring in the piëzo element as according to A. Reyes Reyes [REF].

From the laser the light is branched using a beam splitter with one beam going to a detector, and the other send through the cavity in which the gas to examine sits. Part of the light is absorbed in the cavity as according to the absorbance profiles of the molecules constituting the gas. The remaining light exits the cavity and is measured at the next detector. These two detectors measure the light entering the gas $I\_i$ and the light exiting the gas $I\_o$ as necessary to determine the total absorbance in accordance with equation [REF]. The length of interaction of the light with the gas $variable$ is measured using a laser distance meter [REF Zhe].