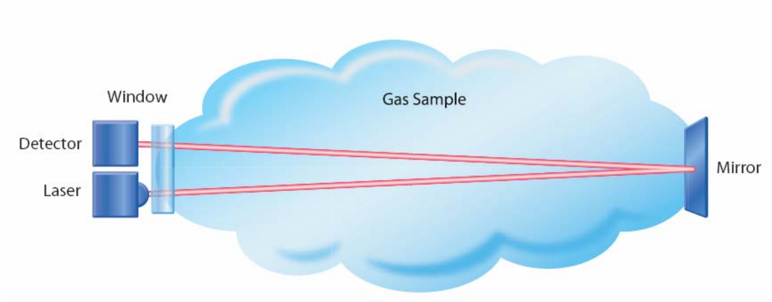
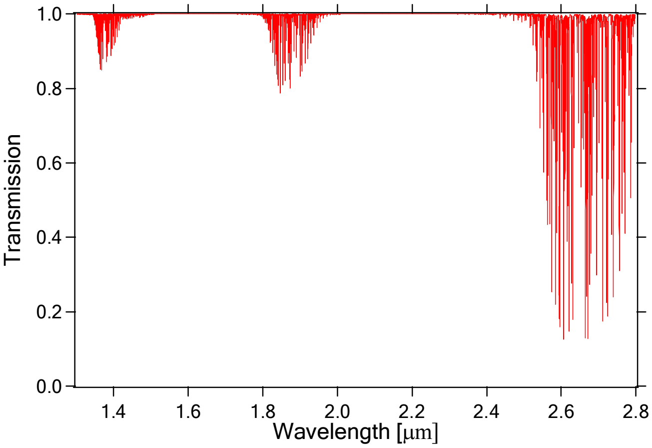
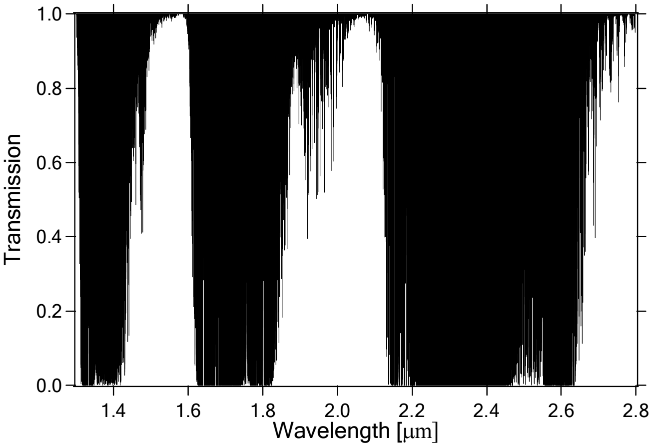
Tech Note:
Tunable Laser Diode Spectroscopy (TDLAS)

Spectral Features:



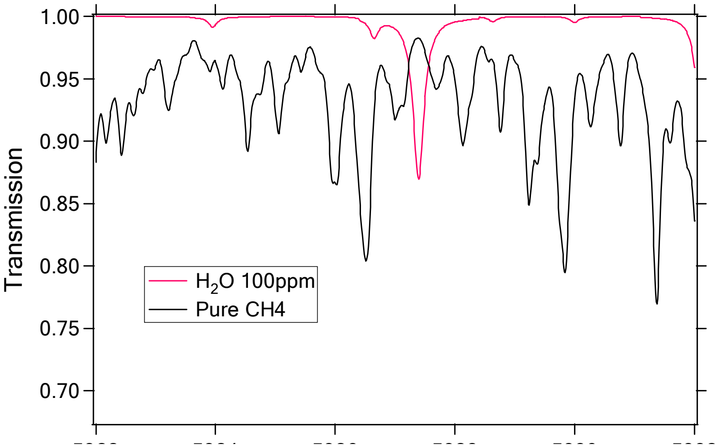
Absorption spectroscopy is a technique used to measure the amount of light absorbed by a gas. The amount of light absorbed by a target gas at a specific wavelength is proportional to the amount of the gas in the path of the light. The target gas is the gas being measured; for example the amount of water vapor in a sample of air can be measured. As shown above, a beam light is passed through a sample and the amount of light lost (absorbed by the target gas) is measured by a detector. The target gas does not absorb all light, but a predictable amount of very specific wavelengths of light. If the light's wavelength is adjusted, the amount of light (power) observed on the output will vary accordingly.





An absorption spectrum diagram shows the amount of light absorbed by a material through a range of wavelengths. The graph on the top right is a diagram for water vapor with the wavelength on the X axis and the transmittance on the Y axis. Transmittance is similar to absorbance except it shows how much light gets through the gas (the amount of light detected) rather than the amount absorbed. A value of 1.0 on the Y axis means all of the light is transmitted through at that wavelength. You can see three regions on the water spectrum graph where light is absorbed. A traditional absorption spectroscopy technique would be to measure the absorption of one of these regions. This is a good technique as long as there are no other gases in the sample that absorb at the same wavelength. The graph on the lower right shows methane transmittance in the same wavelength range as the diagram for water. For measuring moisture in methane, traditional techniques do not work because methane has a much stronger absorbance in the same regions on the graph and completely drowns out the measurement.

The solution to this problem is to "zoom in" to the individual peaks of the spectrum and find a location along the X axis where the peaks do not interfere very much (or not at all). The graph below shows the same spectrums as above except it is expanded around the 1.9 micron wavelength. The individual peaks are about 0.3 nanometers wide and the moisture peak can be measured and discriminated from the methane. As long as these isolated or semi-isolated peaks can be found and the spectrometer used to measure the peaks has adequate resolution (low signal-to-noise), these features can be analyzed to measure target gas concentrations down to part-per-million (ppm) or part-per-billion (ppb) levels.



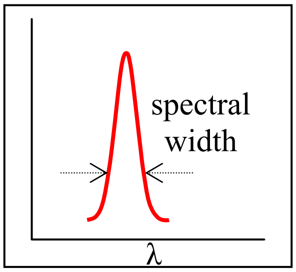
Beer's Law:
As indicated above, the amount of light absorbed by the gas is proportional to amount of the gas present in the light's path. Beer's Law says that light will be absorbed by molecules such that the absorbance (A) is a function of the light beam's path length (l), the density of the gas being measured (d), and the particular absorptivity coefficient (ε) of the chemical species and that the absorbance (A) is a function of the initial light power (P_0) and the power at the detector (P) as shown in these equations:

$$A = ld\varepsilon \ \ \& \ \ A = -\mathrm{Log}_{10}(P/P_0) \rightarrow d \propto (P_0 - P)/P_0$$

Since P is relatively close to P_0 (or P/P_0 is close to 1), and the path length and the absorptivity coefficient are fixed values, you can substitute, expand the log and simplify the equations to show that d is proportional to $(P_0-P)/P_0$. In essence, the target gas density (d) can be determined by measuring P_0 and P with the spectrometer.

Tunable Diode Lasers:
The SpectraSensors TDLAS sensor utilizes a laser diode as the light source. The laser diode allows the instrument to target very specific wavelengths and is an extremely reliable component.

Figure 1 shows an example with wavelength on the X axis and detected power on the Y axis. The laser diode emits roughly a 0.03 nanometer wide spectrum, which is an order of magnitude smaller than any spectral feature being measured.



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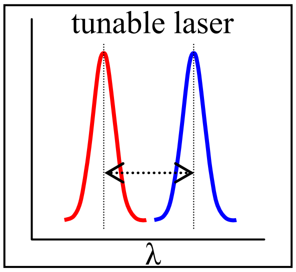

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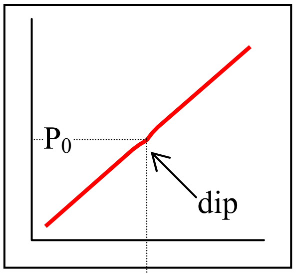
The laser can be "tuned"; meaning the center wavelength of the spectra band can be adjusted by changing the current to the laser as shown in figure 2. In TDLAS, the laser is tuned across a range of wavelengths as it passes through the sample gas and the absorption is measured across that scan (the scan wavelength range is about 1.5 microns = 1500 nanometers). If you were to graph that data with the current on the X axis, and the detected energy on the Y axis, it would be a straight, positively sloped straight line (see figure 3). By design, the straight line actually contains a small dip where the target gas absorbed at the wavelength corresponding to that laser current. The center of the dip represents the wavelength of interest.

Since the scan range is much wider than the spectral feature, it is assured that the center of that peak will be found in the scan. This and the fact that diode lasers are very stable explains how the system compensates for slight drifts in the X axis automatically over long periods of time (years). The absorption measurement itself is explained below.

Measurement technique:
Compensating for possible contamination of the mirror must be considered. The amplitude of the dip (or peak) is a direct result of the absorbance but is not used alone to determine absorbance. Imagine what effect there would be on the curve in figure 3 if the mirror became partially obstructed over time (assuming everything else was the same). The amplitude of dip would change a little, and the entire curve would shift down, both in the exact same ratio (figure 4 – blue line).



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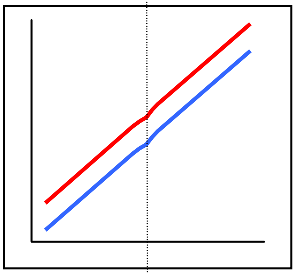
So, changes in the target gas concentration change the amplitude of the dip and overall reductions of the light (the attenuation) changes the amplitude of the dip as well as cause the whole curve to shift up or down. Using a ratio of the absorbed light over the total light detected compensates for and eliminates the effect of the partially blocked mirror! In other words, if only 10% or 50% of the light were getting through, the ratio would not be different and the measurement would not be affected. If the mirror becomes very dirty, not enough light will get to the detector and the power cannot be measured at all. The system checks during every scan for a minimum amount of light. If that test fails, the system will show a "power fail" error indicating that the mirror must be cleaned or something else is wrong.



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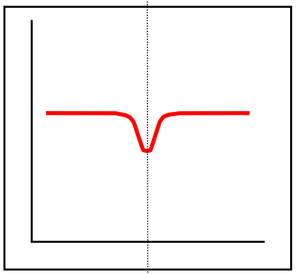
Since the dip in the line is small relative to the overall curve, the signal-to-noise ratio would be high if a direct measurement of the dip were used. To achieve a more sensitive measurement and filter out noise, a method called "second harmonic phase-sensitive detection" is used. This electronic technique will not be fully explained here, but the effect is to filter noise and to condition the curve as follows. Starting with the dip in figure 3, and correcting for the slope plus greatly increasing the scale, the result is something like the peak in figure 5. The second derivative of this curve results in a curve like that in figure 6. Using this "second harmonic" curve (the "2f" curve), the peak-to-peak (pp2f) value is measured. If you divide pp2f by the power (pp2f/P), this value is proportional to $(P_0\text{-}P)/P_0$ which is proportional to the concentration as described in the previous section.



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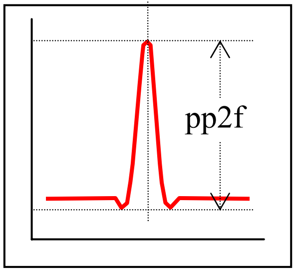

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