Studies in Saturated Absorption Spectroscopy and its Applications to Optical Force Experiments

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Abstract

Saturated Absorption Spectroscopy (SAS) is a technique used to extract a precise transition frequency between atomic states that reduces Doppler broadening. Thus, a laser can be locked to a single atomic frequency.

Background

- **Doppler Broadening** is the widening of spectral lines due to the random motion of atoms in a gas. The atoms don't travel in one uniform direction, resulting in a wide frequency range. Doppler broadening is typically two orders of magnitude larger than a spectral line's natural line width.

$$f_{Doppler} = (\frac{v}{c}) f_{Optical}$$

- **Saturation** occurs when a material is inundated with light such the material no longer responds to additional stimuli.

SAS Overview

SAS aims to generate a high-resolution absorption profile of spectral lines. The SAS technique overcomes Doppler broadening by using a beam that saturates the atoms with light (pump beam) so that no absorption occurs for atoms that have no Doppler shift relative to the second beam (probe beam).

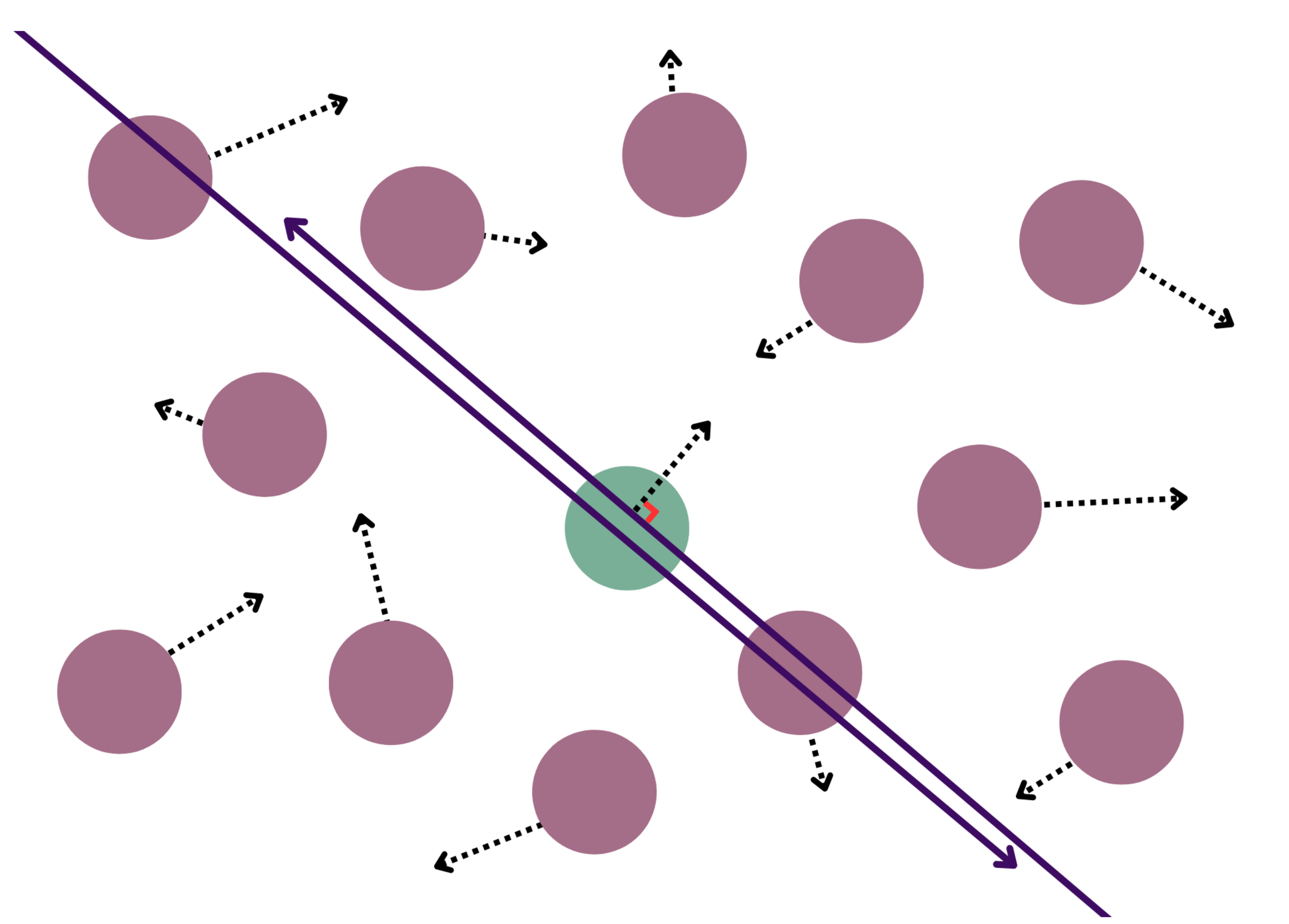

Figure 1. Atoms moving perpendicular to the beams experience no Doppler shift, relative to them. These are the atoms that absorb probe light.

SAS Setup

- **Two counter-propagating beams** that stem from the same laser enter the cell of metastable helium atoms
- **Strong pump beam** drives the cell with excess light, saturating the atoms
- **Weak probe beam** moves through the cell on the same plane, and atoms moving perpendicularly to both beams transmit light as a narrow signal.

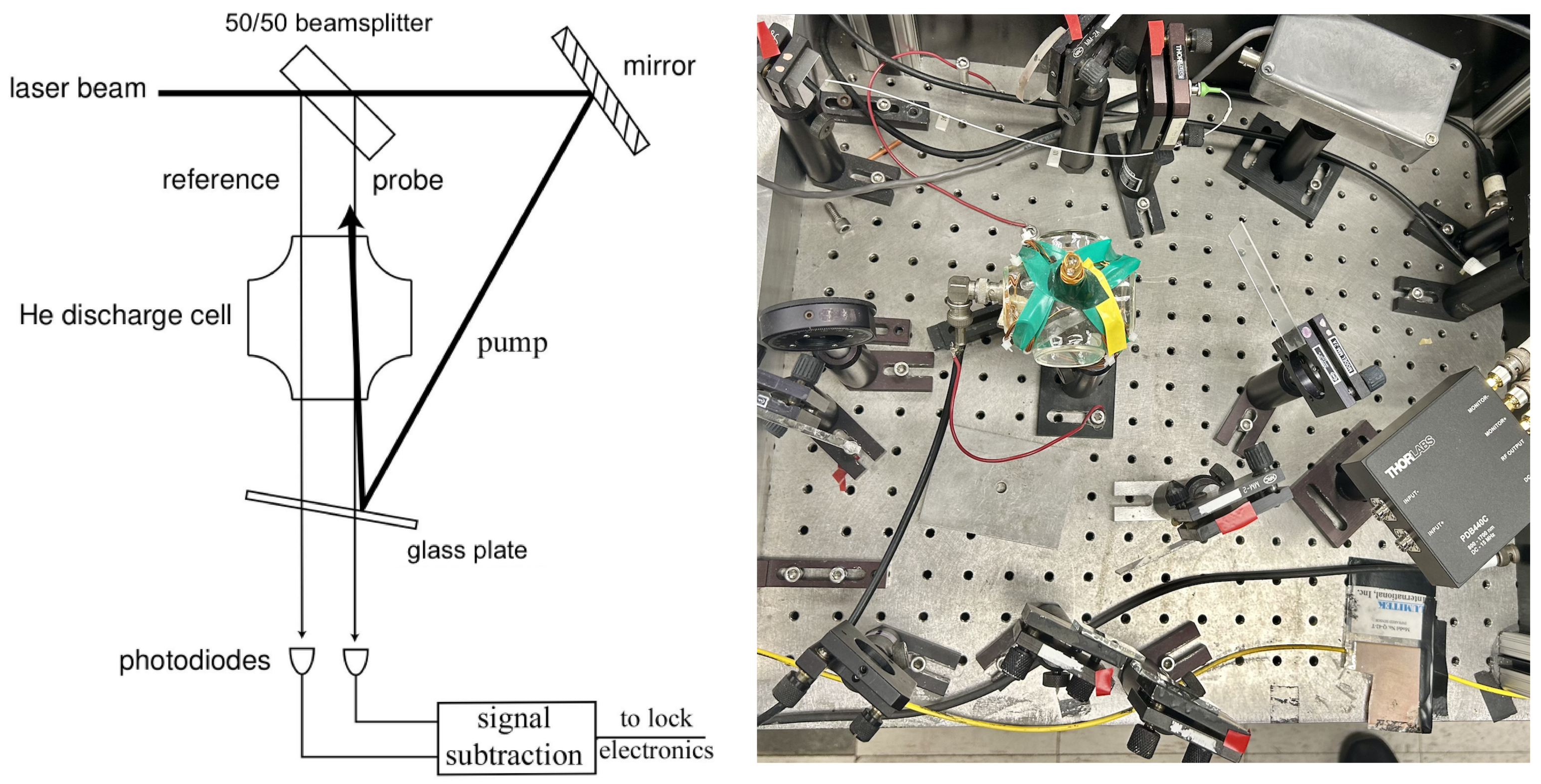

Figure 2. Infrared SAS setup (schematic and lab view) [4]

Resulting Signal

The absorption profile when there is no pump beam present is shown to have a wide Doppler width. When there is a pump beam, there is a spike at the resonant frequency because atoms with no Doppler shift relative to the probe beam are not able to absorb. When we subtract the two plots, we obtain a singular narrow spectral peak.

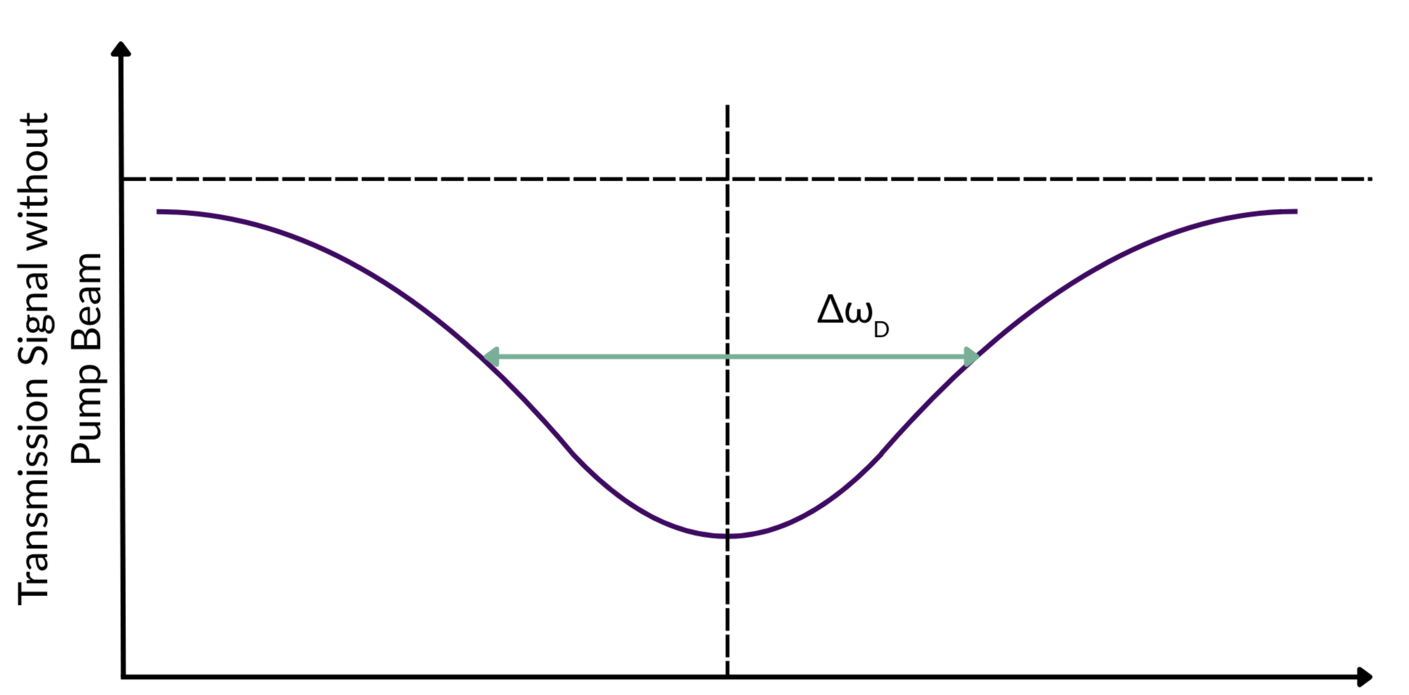

Figure 3. Absorption spectra without the pump beam [4]

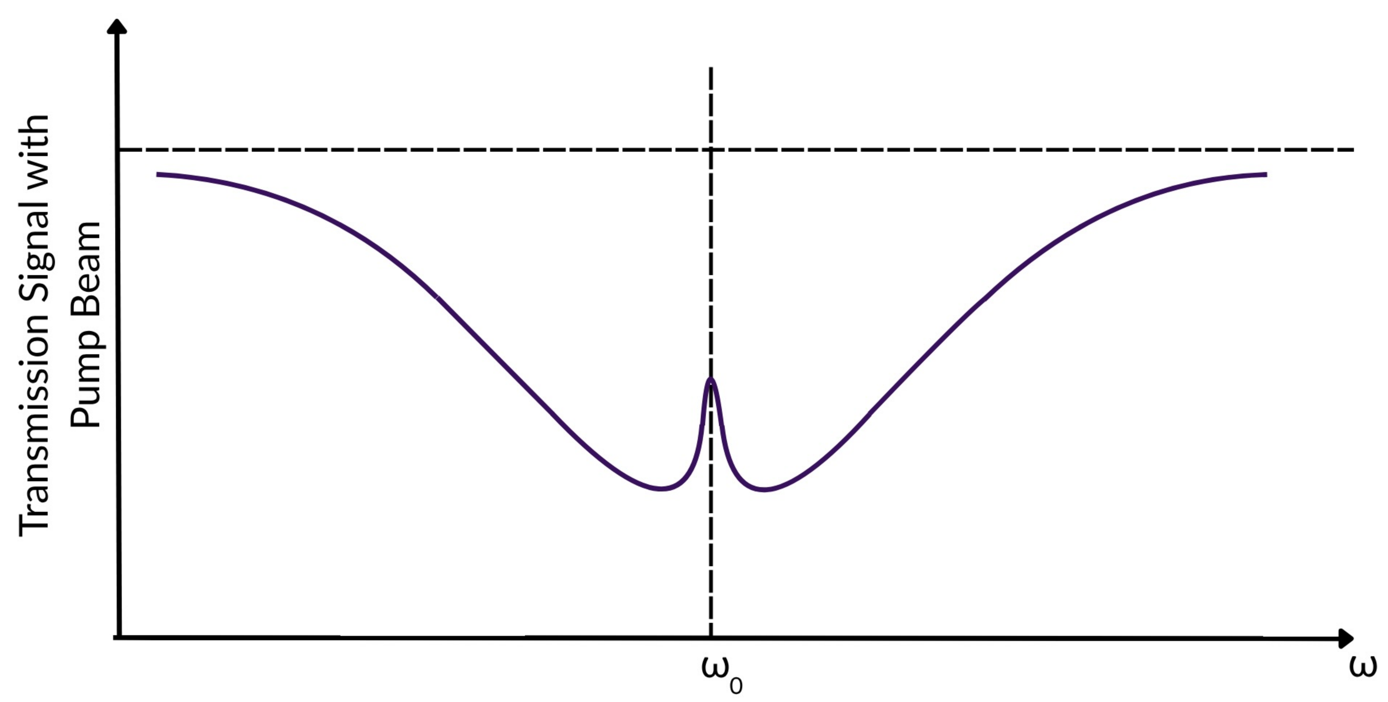

Figure 4. Absorption spectra with the pump beam [4]

Application: Optical Force Experiments

Conservation of momentum deflects atoms when periodic pulse sequences are applied. By stimulated emission, which occurs when light collides with an excited atom, additional light is produced that's moving with the same direction and energy. Optical forces have the capacity to move matter in a precise manner. SAS ensures that the frequency of the incoming beam is stabilized, allowing for further refinement of its application.

Conclusion

With SAS's ability to effectively stabilize a laser to a specific transition frequency, it has numerous applications in optical force experiments, including ongoing ARP and STIRAP projects.

Acknowledgments

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