Locking a Diode Laser to a Two-Photon Atomic Transition

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Introduction

Two-Photon Absorption

Our project aims at using a Diode Laser and a Rubidium cell to observe and study two-photon absorption of the Rb atoms. The process presents various challenges like stability, temperature variation, laser feedback, availability of photons, etc. We aimed to produce a stable experimental setup that would consistently perform the task of two-photon absorption allowing us to study spectroscopy for Rubidium. Furthermore, we also had a goal of locking the diode laser at the resonant frequency which would help our setup in terms of stability and consistency. When the laser is locked to a two-photon atomic transition, the same wavelength of light would have applications in entangled two-photon absorption. Entangled two-photon absorption would be studied for Rb.

The Diode Laser

The Diode Laser was operated using a MOGlabs Diode Laser Controller (DLC). The DLC allows us to perform laser tuning to our precise requirements. One way to control the laser frequency is to use the DLC to control the diode current. The frequency of the laser can also be tuned by using a piezo electric transducer (PZT) inside the laser. This tuning changes the angle of the mirror inside the laser. The different angles of this reflected beam allows us to get different wavelengths of light. PZT allows laser tuning at the sub-nanometer scale.

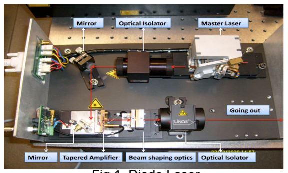

Fig 1. Diode Laser

Spectroscopy of Rubidium

Absorption occurs when the laser is exactly in resonance with an absorption line of the molecules.

Doppler Broadened Absorption:
In practice the molecules have thermal motion at room temperature. If a molecule is moving towards the laser beam with a velocity v_z, it sees the laser at a higher frequency (shorter wavelength) compared to the resonance frequency f. When a molecule is moving away from the laser, it sees a lower frequency (longer wavelength) compared to the resonance frequency f. The appearance of these frequency shifts is called the Doppler effect and it is proportional to the velocity v_z. $\delta v = f \times (v_z/c)$
In this equation, δv is the Doppler broadening of the frequency of the laser, f the resonance frequency and c the speed of light. It means that a laser exactly in resonant with an absorption line of a stationary atom will not be in resonance with the same absorption line in a moving atom.

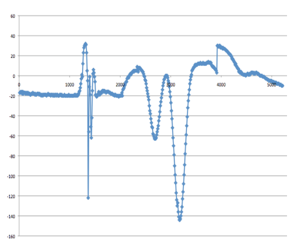

Fig.2. Doppler broadened absorption 1-photon absorption (x axis = frequency in Hz)

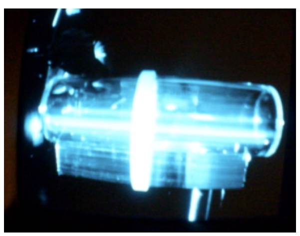

Fig.3. Picture of the Rb cell when we locked the laser to a 1-photon absorption

Doppler-free Absorption:
A Doppler-free signal can be obtained by directing the pump beam all the across towards the other side of the rubidium cell (as shown in Fig.2) and then sending it backwards (towards the source). The pump beam counter propagates through the Rb cell overlapping with one of the probe beams. In the overlapped region the atoms interact with both beams. With this setup, a Doppler-free signal is obtained by subtracting the hyperfine structure for the Doppler broadened structure.

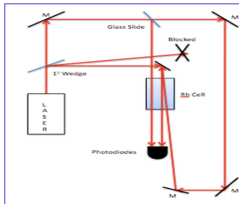

Fig.4. Basic setup for obtaining a Doppler free for 1-photon atomic transition.

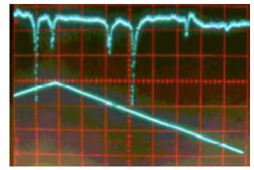

Fig.5. Example of a Doppler free absorption signal (data from Thijs Hoogeveen)

Two-photon Absorption:
In this type of absorption the energy of two photons is used to excite the atoms to a higher energy level. The Selection Rule when absorbing two photons is ΔL = 0, ±2. The energy of the first photon excites the atom to a virtual state and the energy of the second photon (that strikes at almost the exact same time) excites the atom to an allowed energy state. Only the pair of photons that have their total energies equal to the energy differences of the allowed energy states can cause two-photon absorption. A beam of high enough intensity and the right wavelength is sufficient to get a Doppler-broadened 2-photon absorption signal. For obtaining a Doppler-free 2-photon absorption signal it is necessary to have a counter-propagating beam. For achieving this we decided to use a curved mirror that sends the beam back towards the source. This meant that the beam would be re-entering the laser head. This can be damaging for the laser and so we needed to prevent the counter-propagating beam from reaching the source. Thus, we used an optical isolator as a simple solution for this problem.

Conventional Two-photon Absorption

The energy schematic shows how the two photons with a wavelength of 778.1 nm each are absorbed and the resulting de-excitation results in the emission of blue light at 420.3 nm. Also, it was important to focus the been in the Rubidium cell so that the probability of absorption was increased. This happens because the absorption is directly proportional to the square of intensity. We used a =7.5 cm lens and a curved mirror with R = 5 cm. The mirror retro-reflects the beam to the same focus. We also heated the Rb cell to a temperature of 125^0 C to increase the density of Rb in the centre of the cell. A higher density of Rb allowed us to a higher probability for 2-photon absorption. We used a photo multiplier tube (PMT) to detect the fluorescence in the form of blue light. We had a voltage across the PMT which was in the range of 800V to 1200V. The filter in front of the PMT only allows blue light to enter the PMT. For achieving sufficient fluorescence, it is necessary to use as many of the available

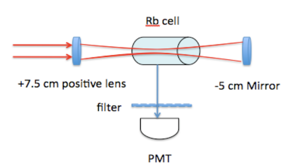

Fig.6. Focusing of the beam inside the Rb Cell

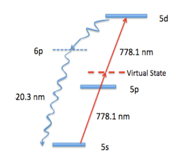

Fig.7. Energy Schematic

Two-Photon Locking Setup

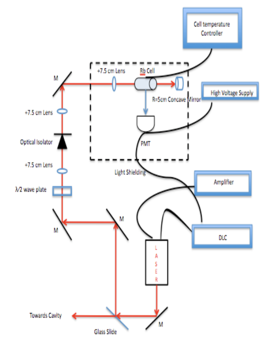

Fig.8 Final experimental setup for 2-photon atomic transition (diagram)

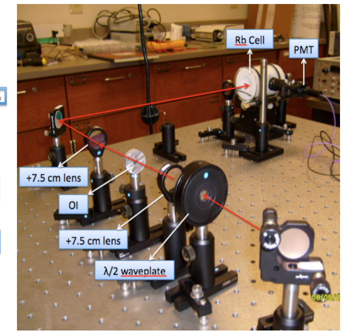

Fig.9. Part of the final experimental setup for 2-photon atomic transition (picture)

Principles of Locking

Locking the diode laser is vital for studying entangled two-photon absorption. The atoms absorb the energy to give two-photon absorption only at the resonant frequency. Furthermore, the number of photons available for this absorption is not very high and thus this process needs to be optimized. Locking the laser allowed us to lock the laser at the resonant frequency. Thus, most of the photons were entering the Rubidium cell with a good chance of getting absorbed so that we can observe fluorescence.

Characteristics of a useful Error Signal:
The DLC can be used to generate an error signal. This error signal is created using the photo-signal obtained using the DLC photodiodes. An error signal makes the locking process possible. The DLC locks at the zero crossing on the oscilloscope. The DLC can be used to adjust the error signal so that the laser frequency can be locked. The DLC also has an option of using an externally generated photo-signal. This allowed us to use a photo multiplier tube and connect it to the DLC for generating an error signal. For our setup, locking to the side of the error signal of a Doppler broadened peak is adequate. The DLC is designed so that it locks to the peak that is closest to the zero crossing signal. We also considered using the peak locking technique where the resonance is shifted so that the signal is generated at the zero signal when the laser is at the frequency of a peak.

Future Work

1.We were able to finish the setup shown in Fig.7. We managed to get the Doppler-broadened signal for 2-photon absorption. However, we did not manage to get Doppler-free signal for 2-photon absorption. Thus, realigning the curved mirror is a work for the future. It should be realigned so that the retro-reflected focus is at the same location as the focus of the incoming beam. It is also important to make sure that these focuses overlap at the centre of the cell.
2.One more project for the future is to improve the signal/noise ratio of the PMT signal. We did not get the best signal because of the external stray light that was affecting the signal. It is also important to make an imaging system to reduce background. This can be done by using a lens and an aperture by placing the lens at a distance of 2f from the PMT and the centre of the cell.

References

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Acknowledgements

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