Abstract

Spectroscopy and stabilization of the laser at a particular transition is key in the modern area of atomic and optical physics. The present thesis details the mechanism of induced atomic coherence between multi-level atomic system driven by lasers and their role in the absorption and fluorescence spectrum. The theoretical study presents a frame work to identify the nature and the role of interference between the excitation paths associated with the Autler-Townes (AT) peaks (i.e., a pair of transitions from the ground state to the dressed states) in a multi-level system. In three-level system the excitation paths associated with the two AT peaks interferes pair-wise and the nature of interference is very simple which can be constructive, destructive or no interference depending upon the decay rate of the states coupled by the strong control lasers. In four-level system the nature of interference is more complicated but again the excitation paths associated with all the three AT peaks interferes pair-wise. For any system, if the decay rate of the levels coupled by the control lasers are equal then there is no interference between any of the excitation paths associated with the AT peaks.

We further studied the saturated fluorescence spectroscopy which is a very useful spectroscopic technique for weak transitions. In the study, the Doppler-free fluorescence dip in the fluorescence spectra is caused by velocity selective saturation (VSS) effect and the dip is further modified by velocity induced population oscillation (VIPO) effect. The VIPO effect is caused by the beating of two counter-propagating electromagnetic fields in a moving atomic frame (due to opposite Doppler shift for a given velocity). The line-shape of the saturated fluorescence dip is sensitive to the laser beam misalignment in the case of the atomic beam. The shifts of the fluorescence dip is dependent on the average velocity of the atomic beam and the angles of misalignment of the laser beams.

The theoretical study is experimentally utilized for double resonance spectroscopy at infrared ($5S_{1/2} \rightarrow 5P_{3/2}$) strong transition and blue ($5S_{1/2} \rightarrow 6P_{1/2}$) weak transition in Rb atom. The double resonance (at 780 nm and 421 nm) is implemented using EIT effect in a V-type system and enhanced absorption (EA) effect in optical pumping system. The scan non-linearity of the blue laser (which is the dominant source of error in the experiment) is minimized by using acousto-optic modulator to shift the laser frequency within a small range of frequencies around the neighboring hyperfine level. The hyperfine splitting of the $6P_{1/2}$ state is measured with a precision of < 400 kHz and the magnetic dipole hyperfine constant is also calculated.

We further utilized VIPO at infrared transition, VSS at blue transition and the combination of the two effects to resolve closely spaced hyperfine levels of a weak transition by eliminating the residual (or partial) two-photon Doppler broadening in a wavelength mismatched double resonance spectroscopy. The double resonance experiment is conducted on $5S_{1/2} \rightarrow 5P_{3/2}$ strong transition (at 780 nm) and $5S_{1/2} \rightarrow 6P_{3/2}$ weak transition (at 420 nm) in Rb atom at room temperature. The residual Doppler broadening is caused by the thermal motion of the atoms in the vapor cell. The elimination of the partial Doppler broadening using the VIPO and VSS effects is followed by the subtraction of the broad background of the two-photon spectrum. Since the VIPO and VSS effects are phenomena for near zero velocity group atoms, the subtraction gives rise to Doppler-free peaks and the closely spaced hyperfine levels of the $6P_{3/2}$ state in Rb are well resolved. The resolved peaks with narrow linewidth, are important for stabilizing the blue laser at a particular transition (i.e., for tight laser locking) for future goals of laser cooling and trapping at this transition. The spectroscopy and stabilization of the blue laser is also beneficial for quantum information processing with coherent excitation of Rydberg states in Rb atoms.