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Original

A laser spectroscopy system with combined absorption, polarization rotation and fluorescence detection to study two photon transitions in atomic rubidium

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Abstract

The design and construction of an experimental system for studying two photon spectroscopy processes in atomic rubidium is presented. It is designed to measure absorption and polarization rotation induced by any of the two laser beams and also the visible fluorescence that results from decay of the excited states. Two home-built diode lasers are used to produce the optical fields that later interact with room temperature rubidium atoms. Using counterpropagating beams allows velocity selection of the groups of atoms that interact with both laser beams. The system was tested in the 5 S → 5 $P_{3/2}$ → 5 D_j ladder energy level configuration of atomic rubidium. Blue fluorescence (420 nm) that results from decay of the intermediate 6P_j states is filtered and then measured with a photomultiplier tube. Absorption and fluorescence spectra provide mutually complementary information about the interaction between the rubidium atoms and the two optical fields.

Keywords: Laser spectroscopy; Two-photon transition; Rubidium

1. Introduction

High-resolution laser spectroscopy free of Doppler broadening has made substantial progress through the study of the interaction between two optical fields and an atomic medium, such as an alkali metal vapor. This progress has also brought improvement in laser stabilization techniques that are commonly used in atom manipulation such as laser cooling and trapping (Metcalf & Van der Straten, 1999). The combination of precisely controlled experiments and the development of theoretical models is a key factor in the advance of high-resolution laser spectroscopy. The agreement between experiment and theory is quite satisfactory under many experimental circumstances (Harris et al., 2006; Himsworth & Freegarde, 2010; Noh, Moon, & Jhe, 2010; Pearman et al., 2002; Smith & Hughes, 2004). For the purposes of this article, one can broadly classify the experiments that use atomic transitions induced by two photons in two groups. In the first one, the effect of the light atom interaction is observed in the modification of the light as it is transmitted through the atomic medium (Auzinsh, Budker, & Rochester, 2010). There are changes in both absorption and polarization of a probe light beam as it passes through an atomic medium interacting with optical fields. In the second group of experiments, the light produces excited states in the atoms that can be detected, for instance, by looking at the atomic fluorescence. In these experiments one measures the atomic population in the excited states. The 5 S → 5 D_j two-photon excitation in atomic rubidium provides very good examples of both types of experiments. Absorption of a probe beam in the 5 S → 5 $P_{3/2}$ → 5 $D_{5/2}$ stepwise

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excitation allows the study of electromagnetically induced transparency (EIT) in a Doppler broadened medium (Badger, Hughes, & Adams, 2001; Drampyan, Pustelny, & Gawlik, 2009; Fulton, Shepherd, Moseley, Sinclair, & Dunn, 1995; Gea-Banacloche, Li, Jin, & Xiao, 1995; Li, Jin, & Xiao, 1995; McGloin, Dunn, & Fulton, 2000; Moon, Lee, & Kim, 2005; Moon & Noh, 2011a, 2011b; Noh & Moon, 2012; Sargsyan, Bason, Sarkisyan, Mohapatra, & Adams, 2010; Sargsyan, Sarkisyan, Krohn, Keaveney, & Adams, 2010; Wielandy & Gaeta, 1998; Xiao, Li, Jin, & Gea-Banacloche, 1995). Examples of fluorescence detection in this stepwise excitation are the two-photon experiments performed either with a single frequency or two different frequencies (Hamid, Çetintaş, & Çelik, 2003; Nez, Biraben, Felder, & Millerioux, 1993, 1994; Ryan, Westling, & Metcalf, 1993; Sanguinetti, Mure, & Minguzzi, 2007; Touahri et al., 1997), electron shelving (Thoumany et al., 2009), frequency up-conversion (Meijer, White, Smeets, Jeppesen, & Scholten, 2006), four wave mixing (Akulshin, McLean, Sidorov, & Hannaford, 2009), direct frequency comb spectroscopy (Marian, Stowe, Felinto, & Ye, 2005). These types of experiments have also been developed for advanced undergraduate laboratories (Jacques, Hingant, Allafort, Pigeard, & Roch, 2009; Olson & Mayer, 2009; Olson, Carlson, & Mayer, 2006). In this work we present a two-photon spectroscopy setup in atomic rubidium in which it is possible to simultaneously detect the absorption and/or rotation of polarization of one of the two excitation light components and the fluorescence of an spontaneous decay channel. Detection of the fluorescence light provides complementary information to the one obtained by performing velocity-selective polarization spectroscopy of room temperature rubidium atoms (Colín-Rodríguez et al., 2015; Flores-Mijangos, Ramírez-Martínez, Colín-Rodríguez, Hernández-Hernández, & Jiménez-Mier, 2014; Hernández-Hernández et al., 2009). This paper is structured as follows. In Section 2 we review the 5 S, 5 $P_{3/2}$, 5 D_j ladder system in atomic rubidium, including the fluorescence decay paths. In Section 3 we present the experimental setup. Details about the construction of our diode lasers and the fluorescence detection system are also given. Examples of experimental spectra obtained with this setup are shown in Section 4. Finally, conclusions are presented in Section 5.

2. The 5 S → 5 $P_{3/2}$ → 5 D_j two-photon transition in atomic rubidium

To understand the different spectroscopy experiments that are performed in our setup we present an energy level diagram of atomic rubidium in Figure 1. The values of the total angular momenta F and hyperfine structure splittings shown here pertain to ^{85}Rb, and a similar diagram can be obtained for ^{87}Rb. In our setup (see below) a continuous wave (CW) diode laser at 780 nm is used to excite room temperature atoms from one of the hyperfine components of the 5 S ground state into the 5 $P_{3/2}$ state (the rubidium D_2 line). A second CW diode laser beam at 776 nm, counterpropagating with the first one, provides a photon for excitation into the 5 D_j (j = 3/2, 5/2) hyperfine manifolds. After this two-step excitation the atoms in the 5 D_j state decay back to the ground state. One of the decay paths is by cascade

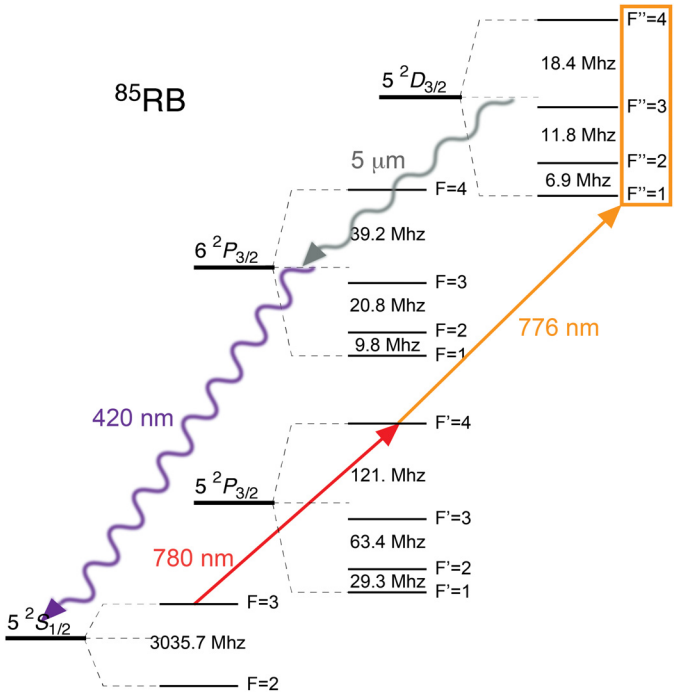

Figure 1. Energy-level diagram for the 5 $S_{1/2}$ → 5 $P_{3/2}$ → 5 $D_{3/2}$ of atomic ^{85}Rb, including the hyperfine states.

emission of an IR photon (5 μm) into the 6 P_j state, followed by emission of a 420 nm photon. Detection of the excitation process can be made by measuring changes in the absorption or rotation of the linear polarization of one of the laser beams (Flores-Mijangos et al., 2014; Hernández-Hernández et al., 2009) or by detection of the emission of a 420 nm fluorescence photon. The hyperfine splitting of the 5 $S_{1/2}$ state in atomic rubidium is larger than the D_2 line Doppler width at room temperature (≈500 MHz). Therefore, the total angular momentum F of the initial step in our excitation ladder is well defined. However, the hyperfine splitting of both 5 $P_{3/2}$ and 5 D_j states is smaller than the D_2 Doppler width. If the frequency of one of the two lasers is fixed, then by scanning the frequency of the second laser one can perform velocity selective (Flores-Mijangos et al., 2014; Hernández-Hernández et al., 2009) spectroscopy resulting in lines that are not broadened by the Doppler effect. The resonant frequency ν_2 and the velocity of the group of atoms that simultaneously interact with both laser beams is given by the solution of the set of equations

$$\nu_a = \nu_1\left(1 - \frac{v}{c}\right)$$
$$\nu_b = \nu_2\left(1 + \frac{v}{c}\right) \quad (1)$$

where ν_a is one of the atomic resonant frequencies of the 5 S → 5 $P_{3/2}$ hyperfine manifold, ν_b is an atomic resonant frequency of the 5 $P_{3/2}$ → 5 D_j manifold and ν_1 is the fixed frequency of one of the lasers. Here it is important to mention that the transitions must be allowed by the electric dipole selection rule $\Delta F = 0, \pm 1$. In our system we use balanced detection to measure the absorption and polarization of the 780 nm beam used in the first step of the excitation. We add a photomultiplier tube to the system