Vol 12 No 11, November 2003
1009-1963/2003/12(11)/1225-04

Chinese Physics

© 2003 Chin. Phys. Soc.
and IOP Publishing Ltd

An abnormal phenomenon in the saturated absorption spectrum of ^{87}Rb*

He Ling-Xiang(贺凌翔)† and Wang Yu-Zhu(王育竹)

Shanghai Institute of Optics and Fine Mechanics, Chinese Academy of Sciences, Shanghai 201800, *China*

(Received 3 January 2003; revised manuscript received 13 June 2003)

A polarization-type saturated absorption spectrum set-up for ^{87}Rb atom laser cooling and trapping has been established in our laboratory. By changing the polarization components and optical power, enhanced absorption of the transition $5S_{1/2}$ F=2 → $5P_{3/2}$ F'=3 was observed with other transitions and cross-over resonance staying unvaried.

Keywords: energy level, fine structure, saturated absorption spectrum, enhanced absorption
PACC: 3260V, 3300, 3345B

1. Introduction

Laser cooling and trapping has opened up a new field of study in atomic physics.[1−6] Moreover, it helps us to understand some basic physical theories or concepts more deeply, such as the macroscopic quantum state.[7−11] Atoms in a trapped state have the property that the internal degree of freedom is strongly coupled to the external.[12] So it stimulates much interest in focusing on these fields. Now it has been confirmed that super-low-temperature atoms with superhigh density, a large number of atoms condensed in the same state suddenly, i.e. so-called Bose–Einstein condensation (BEC), was realized in the laboratory in 1995.[13] Based on these achievements, the saturated absorption spectroscopy begins to play an important role in these experiments. It can be used for accurate frequency stabilization. In this paper, we report the establishment of a set-up of saturated absorption spectrum. By adjusting some optical elements, we have found some new features, and possible explanations are given.

We measure the D_2 transition of ^{87}Rb atoms. Figure 3 shows the ^{87}Rb saturated absorption spectrum of the $5S_{1/2}$ F=2 to $5P_{3/2}$ F'=1,2,3, transition of ^{87}Rb atoms, where F denotes the hyperfine level of the $5S_{1/2}$ ground state, F' indicates that of the $5P_{3/2}$ excited state. The hyperfine structure results from the spin of the nucleus. It can lead to the separation of the energy levels in magnetic field, i.e. the Zeeman effect. Hyperfine structure of ^{87}Rb is shown in Fig. 1, where F'' denotes the hyperfine level of the $5P_{1/2}$ excited states.

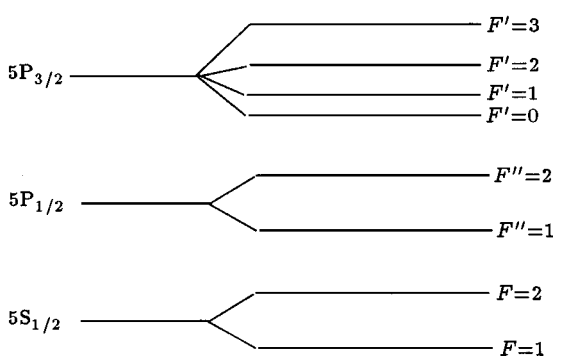


Fig.1. The hyperfine structure of the energy levels of ^{87}Rb.

2. Experimental set-up

The experimental set-up is shown schematically in Fig. 2.

*Project supported by the National Natural Science Foundation of China (Grant Nos 19834060 and 10174086), funded also by the National Fundamental Research Program (Grant No 001CB309307).

†Tel: 021-69918368, Fax: 021-69918800, Email: helingxiang@yahoo.com

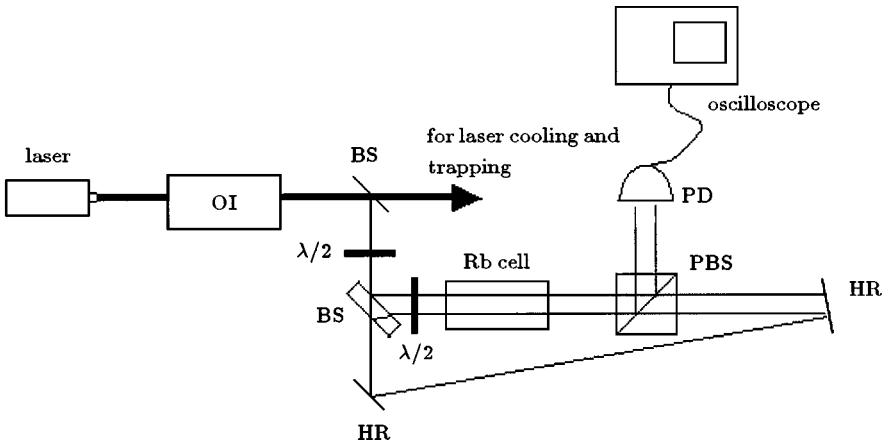


Fig.2. Experimental set-up for saturated absorption spectrum. OI: optical isolator, BS: beamsplitter, $\lambda/2$: half-wave plate, PBS: cubic polarization beamsplitter, HR: high reflection mirror, PD: photodiode.

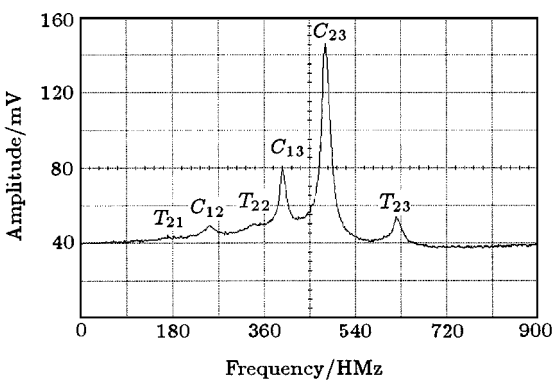


Fig.3. Saturated absorption spectrum of ^{87}Rb transition $5S_{1/2}$ F=2 $\rightarrow$ $5P_{3/2}$ F'=1,2,3 and the other three cross-over resonances. (The frequency has been normalized, and the same for the following figures).

Our laser system (product of TOPTICA) has a maximum output of 500mW, about 3mW output was used for the saturated absorption spectrum. We used a 55cm long ϕ25mm rubidium cell. For simplicity of the structure, we used two half-wave plates, one to change the relative optical intensity of pumping beam and probing beam, and the other to adjust the optical intensity of the probing beam to avoid detector saturation. A polarization beamsplitter is used to coincide the pumping beam and probing beam accurately. The saturated absorption spectrum of ^{87}Rb transition $5S_{1/2}$ F=2 to $5P_{3/2}$ F'=1,2,3 shown in Fig. 3 was obtained with our apparatus, the likeness of which can be found in many other papers.[14] It shows six peaks. T_{23}, T_{22} and T_{21} are transitions of $5S_{1/2}$ F=2 to $5P_{3/2}$ F'=3, $5S_{1/2}$ F=2 to $5P_{3/2}$ F'=2, and $5S_{1/2}$ F=2 to $5P_{3/2}$ F'=1, respectively. And the other three cross-over resonances C_{23}, C_{13} and C_{12} denote transitions $5S_{1/2}$ F=2 to $5P_{3/2}$ F'=2,3, $5S_{1/2}$ F=2 to $5P_{3/2}$ F'=1,3, and $5S_{1/2}$ F=2 to $5P_{3/2}$ F'=1,2, respectively.

We adjust the half-wave plate located between the two beam-splitters to change the power of the probing beam and the pumping beam. As the power of probing beam decreases, the transition and cross-over transition peaks begin to decrease, as shown in Fig. 4.

But when the power of probing beam degrades to a certain value, the peak T_{23}, which is created by the transition $5S_{1/2}$ F=2 $\rightarrow$ $5P_{3/2}$ F'=3, begins to reverse. And at last it attains its minimum transmission value, in other words, it reaches maximum absorption. But at the same time other transitions and cross-over transitions keep in their original transmission direction. When adjusting the other half-wave plate (which is located between the BS and the Rb cell) to give enough optical power of probing beam, namely about 400μW, the same phenomenon appears.

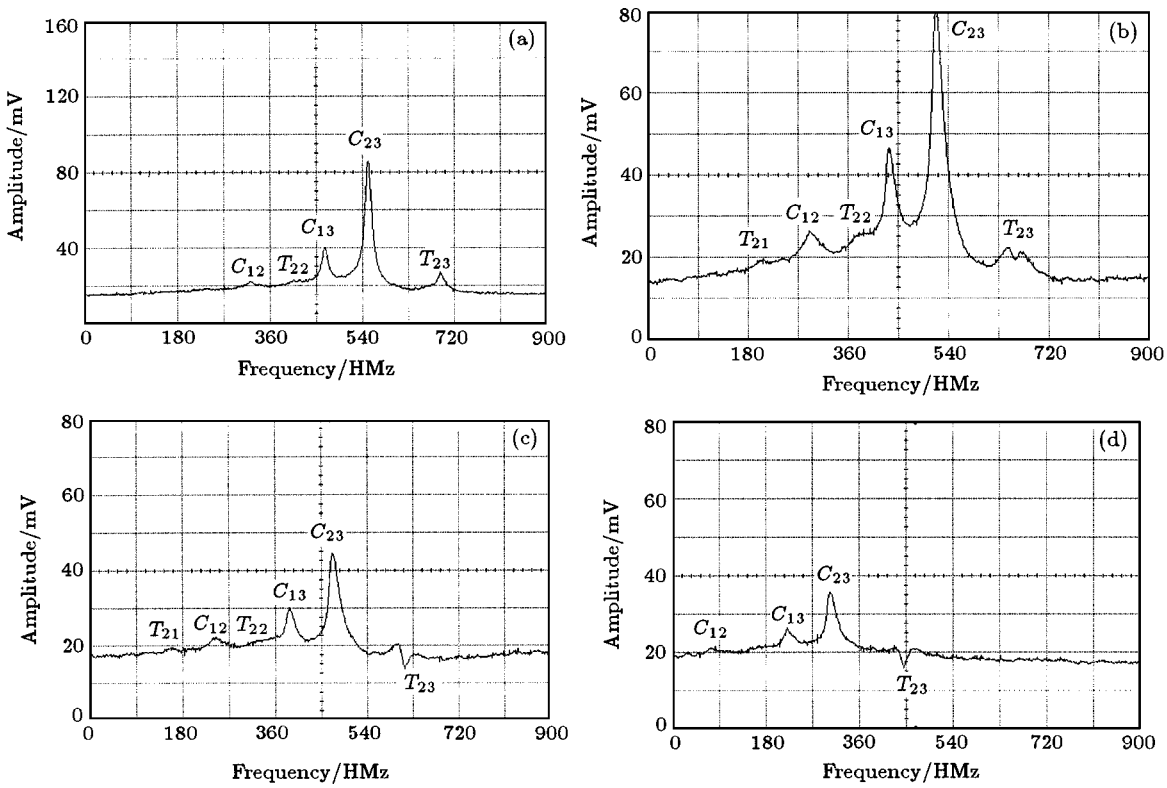


Fig.4. Evolution of transition and cross-over transition peaks, with decrease of polarization components and power of probe beam. From (a)–(d), the optical power of probe beam changed from 3mW to 400μW.

3. Results and discussion

We give a possible explanation for such experimental results. Excitation of atoms in a vapour cell by polarized light produces an unbalanced population distribution of the magnetic sublevels of the atomic state. If the polarization of spontaneous photons is different from that of the absorbed photons, the atoms will eventually stay in another state different from the original one when atoms return from the excited state to the ground state. So it will induce population redistribution. Moreover, as the result of optical pumping, most atoms will distribute in some states with high probability. In our cases, the state $5S_{1/2}$ $|F = 2, m_F = 2\rangle$ has a greater occupation probability. During our operation of turning the half-wave plate, the polarization will change correspondingly for both pumping and probing beams, which induces a change in the population distribution of the excited state, $5P_{3/2}$. Also under the action of the pumping beam, an atomic coherence is established among these sublevels. Finally, it leads to a redistribution of the ground state, $5S_{1/2}$. So in the state $5S_{1/2}$ $|F = 2, m_F = 2\rangle$ more atoms accumulate, which violates the original absorption balance, and enhances the absorption. Under the simultaneous action of the pumping and probing beams with their perpendicular polarization, transition from $5S_{1/2}$ F=2 to $5P_{3/2}$ F'=3 has great probability in this case, and this transition eventually collapses to its inverted maximum. In the mean time, during the optical pumping process, as the optical power of probing beam decreases, the intensity of all transition peaks degrade.

In summary, a polarization-type saturated absorption set-up was used in our experiment, in which the polarization components of the beams are changeable. The laser has a few milli-watt optical power. By adjusting a half-wave plate, we observed quite regular changes of the spectrum. Especially, the transition $5S_{1/2}$ F=2 to $5P_{3/2}$ F'=3 reverses, as the polarization components of the optical fields of both pumping and probing beams change. These results can help us to understand clearly the redistribution of the atoms in some sublevels during the cooling and trapping process with the change of optical pumping method. By the way, it seems this phenomenon is something like

electromagnetically induced transparency (EIT)[15] effect. But due to the different energy structure used, there is some difference in the results. We cannot get all peaks enhancing their absorption, for the atoms have to be resonant with both pumping beam and probing beam, which oscillate at the same frequency but propagate in adverse directions.

References

[1] Raab E L *et al* 1987 *Phys. Rev. Lett.* **59** 2631
[2] Stoof H T C, Houbiers M, Sackett C A and Hulet R G 1996 *Phys. Rev. Lett.* **76** 10
[3] Myatt C J *et al* 1997 *Phys. Rev. Lett.* **78** 586
[4] Lett. P D *et al* 1988 *Phys. Rev. Lett.* **61** 169
[5] Aslan M and Tittmann B R 1999 *Chin. Phys.* **8** S78
[6] Wang H B *et al* 2002 *Acta Phys. Sin.* **51** 1011 (in Chinese)
[7] Lovelace R V E, Mechanian C, Tommila T J and Lee D M 1985 *Nature* **318** 30
[8] Lovelace R V E and Tommila T J 1987 *Phys. Rev.* A **35** 3597
[9] Hinds E A, Boshier M G and Hughes I G 1998 *Phys. Rev. Lett.* **80** 645
[10] Chu S *et al* 1986 *Phys. Rev. Lett.* **57** 314
[11] Long Q, Zhou S Y, Zhou S Y and Wang Y Z 2001 *Chin. Phys. Lett.* **18** 11
[12] Jersy Zachorowski *et al* 1998 *Opt. Applicata* **XXVIII** 239
[13] Anderson M H *et al* 1995 *Science* **269** 198
[14] MacAdam K B *et al* 1992 *Am. J. Phys.* **60** 1098
[15] Li Y Q and Xiao M 1995 *Phys. Rev.* A **51** R2703