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The photoassociation reaction of ultracold atoms

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Abstract. Photoassociation reaction is the process in which two colliding atoms (or the colliding atom-molecule system) absorb a photon to form an excited molecule. Since the researches based on the ultracold atomic and molecular systems have attracted great attention both from theorists and experimentalists, the ultracold photoassociation reaction is becoming an ascendant research field. In this paper, we review briefly the investigation history of the photoassociation reaction for ultracold atoms, especially the basic theory of collision and the photoassociation in different light fields, and the research on the external-field manipulation of ultracold atoms collisions is also prospected.

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Key words: ultracold atoms, photoassociation reaction, collision theory.

1 Introduction

In recent decades, the development of laser techniques have made many new phenomena of laser-atom or laser-molecule interaction observed and investigated, such as ac-Stark shift [1,2], multiphoton ionization [3-7], laser-induced continuum structure [8-10], and photoassociation reaction [11-15], etc. In the investigation of photoassociation, it is found that the temperature of the samples is essential for the optical excitation and emission processes, i.e., the cold samples is beneficial to achieving the photoassociation spectroscopy with high resolution. In addition, the low temperature condition has other advantages that the formed production is more stable, and the reaction can be easily controlled by external fields, due to the translational energy of the system is very low. For the acquiring of low temperature, the laser-cooling technique is an alternative and the obtained temperature can be in the range from a few mK to several μK (ultracold). Another cooling technique is the so-called evaporative cooling, which has been reviewed by

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W. Ketterle [16], E. A. Comell and C. E. Wieman [17]. It can be also used to cool atom to even lower temperatures in the quantum degenerate limit where atomic Bose-Einstein condensation (BEC) occurs [18].

The success of ultracold atom preparation on experiments stimulates and promotes the study of ultracold molecules. Because molecules have vibrational and rotational degree of freedom, and a possible magnetic dipole moment or electric dipole moment provides more possibilities for the manipulation of molecule, the study of productions and applications of cold molecules will be more challenging and pioneering. However, the production of ultracold molecules is of great significance for molecular matter waves [19], highly precise molecular spectrum [20], coherent molecular chemistry [21], quantum information processing [22,23] and so on, so it becomes a very important research topic of the atomic and molecular physics to seek effective methods of producing ultracold molecules. Fortunately the realization of ultracold atoms offers new ways for producing ultracold molecules. According to the ways they are obtained by associating ultracold atoms using external field, either optical field, or magnetic field, the associating scheme can be classified correspondingly into two kinds, i.e., magnetoassociation and photoassociation. Magnetoassociation is also called magnetic Feshbach resonance, in which the magnetic field is used to adjust the interatomic interactions, so that the two colliding atoms form a metastable molecules [24]. Photoassociation is the process in which two colliding atoms absorb a photon to form an excited molecule [25]. Compared with magnetic Feshbach resonance techniques, photoassociation has a lower requirement for ultracold atoms samples, and has the advantages of high efficiency, low energy levels and stable states when producing ultracold molecules. In Some literatures it is also called the optical Feshbach resonance [26].

Photoassociation has been studied both experimentally and theoretically. In 1987, the concept of photoassociation was first introduced by Thorsheim *et al.* [27] Since then, many ultracold diatomic molecules [28-40] have been associated using this technology, but with very low forming efficiency. In 1998, a new method was proposed to solve the above problem, which used stimulated Raman photoassociation technique to form ultracold molecules in alkali metal atomic BEC [41]. Four groups reported the photoassociative production of three different ultracold heteronuclear diatomic molecules in 2004 [37-39,42]. In 2011, Zhang Wei and Cong Shu-Lin *et al.* [43,44] investigated the photoassociation dynamics implemented by a series of asymmetric slowly turned-on and rapidly turned-off laser pulses, and in the same time they also demonstrated the photoassocoation dynamics of ultracold cesium atoms being controlled by varying the corresponding parameter. In 2012, Lin Feng and Zhang Wei *et al.* [15] researched the dependence of photoassociation probability on the cut-off position of the laser pulse. In 2014, Jesús Pérez-Ríos *et al.* [45] have theoretically considered two photo-assisted collisional processes between ultracold particles namely between an atom and a molecule, or between molecules, in order to create ultracold trimers or tetramers. From the introduction presented above, we can see that the photoassociation technology has got great development. To help people understand it systematically, a review of it is necessary.