CHAPTER 1

INTRODUCTION

1.1 Introduction and motivation

A large-scale quantum computer has the potential to hold calculating power greater than the current fastest classical computer. The ultimate computing capability of the quantum computer comes from quantum interference in which a quantum bit or qubit of all parallel inputs simultaneously represents both 0 and 1 state at the same time [1, 2]. In addition, the developed quantum algorithms that involve quantum interference and delayed measurements allow solving certain problems such as a large number factorization and many-body systems, much faster than classical algorithms [3-5]. It has been estimated that with only 50 interaction-controlled qubits, quantum-computing process would outperform of the fastest supercomputer [6]. The supreme calculating capability of the quantum computer will accelerate the expansion rate of frontier knowledge and lead to technological revolution.

In developing quantum computer, the system of neutral atoms individually occupying each site of optical lattices is a strong candidate for realizing physical qubits. In the lattice, each atom in each trap is still detectable and addressable independently [7-10]. As the computational data is encoded into the internal states of the atoms through the employment of the near resonance light, the atoms are allowed to perform as qubits. In the presence of weak stray light, the single atom has long decoherent time, which also means long trapping lifetime. Besides all reasons, aforesaid long range entangling interactions between the trapped single neutral atoms can be varied for on-off switching [11-13]. Though at present, the mainstream research focus on the coherently controlled interactions necessary for in quantum gate operations. The basis structure such as quantum register has been confronting with an obstacle to load the perfect array of the single atoms without lattice vacancy. To resolve this problem, the simplest scheme of preparing "one atom in a single well" is considered. All crucial parameters, which suppress a single atom loading efficiency, must be studied in details to achieve deterministic loading. After that, the scalability from a single atom in a well to single atoms in optical lattices will be straightforward. In summary, a generation of single atom source is not only shown the capability to control the atoms in microscopic scale but it is also worthwhile for realization of a quantum computer.

For past decade, there are several challenging attempts in deterministically preparing a single atom. The cavity-based techniques that trap single atom at the antinode of the standing wave, has a difficulty for loading single atom, gives a low efficiency and are not scalable [14, 15]. The transition from the Bose-Einstein condensate (BEC) to the Mott insulator in an optical lattice could contribute a high efficiency of loading single atom in each site of the lattice [16, 17]. However, the loading time of this route is relatively long because of the complicated BEC generation. An alternative way for the single atom preparation is performing light-assisted collisions [18], where related experimental techniques are much simpler and require shorter loading time. In addition, the light-assisted collision can be employed in arbitrary trap geometries.

As the bimolecular potentials are shifted from the atomic potential levels when two atoms are closed to each other, both red- and blue-detuned light can induce a transition of the atoms, which is the beginning of two-body collision. To avoid the heating effect, the red-detuned light has been used to study the single atom preparation. However the loading efficiency was limited at 50% [9, 18-20] because of the inelastic collision processes where the energy shared after the two-body collision is sufficiently high enough to make a pair loss event. The lack of control over energy shared can be resolved by using the light blued-detuned from the asymptote line of the repulsive molecular potential. In such case, the energy released from the collision is precisely limited through the amount of detuning in such a way that only one of the collisional partners may escape. This has boosted up the loading efficiency to 83% [21], the level number attained before. The blue-detuned light-assisted technique shows signs of pathway for preparing single atoms on demand, since the loading efficiency and the loading time corresponding with this method have a potential to be improved when the dynamics of all crucial parameters are understood.

In this thesis, the light-assisted two-body collisions of cold rubidium atoms were studied for the purpose of enhancing the single atom loading efficiency and gaining knowledge of the collisional processes in the cases of red- and blue-detuned light. To the best of our knowledge, the cold collisions were studied in a scale of huge number of atoms where some information was hidden in the ensemble average [22-25]. To extract the invisible information, an observation of individual collisional events is needed [26, 27]. In this study, we consider in the system such that only two atoms are in trap. The dynamics of the atoms under the influence of applied collision-inducing light are at our interest.

1.2 Outline of thesis

In Chapter 2, the background and relevant theory was described briefly in two parts. The first part of the chapter begins with reviewing the physics of standard trapping and cooling techniques such as Doppler cooling and magneto-optical trap (MOT). An optical dipole trap that confines a single atom is described in the dressed-state picture. The Sisyphus and Polarized gradient cooling (PGC) techniques, which were employed for loading atoms into the dipole trap and cooling the atoms during imaging respectively, are also mentioned at the end. For the second part of Chapter 2, the atomic loss due to the cold collision induced by light is considered. This part begins with explaining the cold collision in the picture of quasimolecular energy levels. Selected theoretical treatments to model the collision processes are mentioned.

In Chapter 3, the methods and apparatus for preparation of cold ^{85}Rb atoms are explained. The standard MOT was chosen for preparing the cold atomic cloud. The MOT apparatus was constructed for the first time in Thailand at the Quantum Atom Optics (QAO) Laboratory. The fluorescence image of the cold atomic cloud at the center of the MOT is shown at the end of the chapter.

To study the cold collision inside the dipole trap, part of this work was conducted at the Otago Atomic Physics Laboratory at the University of Otago in New

Zealand. The apparatus and techniques for loading the cold atoms into the dipole trap are detailed in Chapter 4. The Rb atoms in the dipole trap are detected and the characterization of the single Rb atoms is also presented in the chapter. The ability to prepare both single atom and two atoms in the trap are demonstrated.

The dynamics of two atoms were observed while the laser light was being applied to induce the collision between the atoms. From the two-atom evolution, the individual collisional losses were detected and the result is reported in Chapter 5. The result is separated into two cases that are for the red and blue detuned light. As the simplicity of only two atoms in the trap, the system was simulated to obtain the insight of the light-assisted collision processes. In addition, the effect of the collision light parameters (intensity and frequency) on the single atom loading efficiency was studied. In Chapter 6, all of the results in this study are discussed and concluded.