Calculations on Cold Collisions Between Laser Cooled Alkaline Earth Atoms

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A laser red-detuned from the $^1P_0$-$^1S_1$ cooling transition will cause trap loss from a sample of laser cooled and trapped earth alkaline atoms via three mechanisms: two by excitation to the attractive molecular singlet states at long range ($^1\Sigma_u^+$ and $^1\Pi_g$) followed by state change (SC) to a triplet molecular states at short range. The third mechanism is radiative escape (RE) after excitation to the $^1\Sigma_u^+$-state at long range, and spontaneous decay at shorter range.

We use quantum scattering methods to calculate the light-induced collisional loss of laser-cooled and trapped magnesium atoms for detunings up to 50 atomic linewidths to the red of the $^1S_0$-$^1P_1$ cooling transition. The major isotopes of the alkaline earth atoms have no hyperfine structure to complicate the theoretical studies. We evaluate both the RE and SC mechanisms of trap loss. The RE mechanism via the allowed $^1\Sigma_u$ excitation is dominant for more than about one atomic linewidth detuning. Molecular vibrational structure due to photoassociative transitions to bound states begins to appear beyond about ten linewidths detuning. The SC trap loss via excitation at long range to the $^1\Sigma_u^+$-state and coupling to a triplet state at short range shows the same features as the RE trap loss, but is about one order of magnitude smaller. The SC trap loss via excitation to the $^1\Pi_g$ -state is smaller than via the two other mechanisms, except at very small detuning. The $^1\Pi_g$ SC have vibrational and rotational structure even at small detunings.

For magnesium the short range molecular potentials are available, and show a simple structure, therefore we have chosen this system as our model system. Little is known about the short range molecular potentials for the other alkaline earth diatomics, and we simplify these systems by introducing one effective SC crossing. The coupling at the SC crossing is scaled by the magnitude of the fine-structure splitting of the ^3P atomic state.

The quantum calculations include the 3-dimensional aspects of the collisions by summing over branches and partial waves, and take the effect of a finite temperature into account by thermal averaging over collisions energies. Except for uncertainties in the short range

potentials and the SC coupling strength the trap loss spectra for Mg are complete. The modelling of the other species, allow us to discussed scaling of properties throughout the group II and also for Yb.

The trap loss spectra presented are for a weak probe laser, therefore independent of the cooling laser. We span the temperature range from the Doppler limit for the $^1S_0$-$^1P_1$ cooling and 3 orders of magnitude down covering also the temperatures reached by cooling on the intercombination line.