Collisions of Atoms in Microwave and Laser Fields

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In order to Bose condense spin-polarized atomic hydrogen, a few types of traps have been proposed to isolate the atoms from the walls where recombination takes place. Recently, Agosta and Silvera [1] proposed a microwave trap operating on the b-c electron spin-flip transition at ~ 5 tesla. They made a preliminary calculation of the collisional relaxation loss of atoms in such a trap using dressed atom states. In this contribution the relaxation rates are worked out more completely. Although we mention only the microwave trap explicitly, our theoretical techniques apply also to laser traps.

The dressed states are superpositions of bare levels b and c with admixture depending on detuning δ :

$$\begin{aligned} |1(N)\rangle &= \cos\theta |c,N\rangle + \sin\theta |b,N+1\rangle = \text{unbound state} \\ |2(N)\rangle &= -\sin\theta |c,N\rangle + \cos\theta |b,N+1\rangle = \text{bound state} \end{aligned}$$

with $\cotan 2\theta = -\delta/\omega_1$, where $\omega_1(\underline{r})$ is the local Rabi frequency. The energy splitting of the uncoupled $|c,N\rangle$ and $|b,N+1\rangle$ states is $\hbar\delta$, that of the dressed states is $\hbar\Omega$ with $\Omega = \sqrt{\delta^2 + \omega_1^2}$. The $2(N)$ atoms are trapped in a potential $-\frac{1}{2}\hbar\Omega(\underline{r})$. Our problem is to calculate the decay of such a gas due to spin-exchange and magnetic dipole interactions. It turns out to be possible to express all relevant rate constants in terms of collision amplitudes for bare states, for which rigorous values are available [2]. The values of the latter at about 5 T indicate that we may confine ourselves to collisions with only b and c states as initial and final states, i.e. only dressed initial and final states are to be taken into account [1]. A total number of 15 transitions are then to be considered: from $2(N)2(N)$ to $2(N)1(N)$, $1(N)1(N)$, $2(N)1(N-1)$, $1(N)1(N-1)$,

Our method to calculate these rates is to use dressed-atom states as asymptotic states in two-body collisions. A typical S-matrix element is then $S_{fi} = S_{2(N)1(N), 2(N)2(N)}$. We apply the degenerate-internal-states (DIS) approximation, i.e. we neglect the splitting $\hbar\Omega$ of levels within each of the manifolds. As a consequence we have

$$S_{2(N)1(N),2(N)2(N)} = \sum_{h_1 h_1'} \langle 2(N)1(N) | h_1' h_2' \rangle S_{h_1' h_2', h_1 h_2} \langle h_1 h_2 | 2(N)2(N) \rangle$$

In view of the low temperatures involved, the initial ℓ value is 0 and the final ℓ is 2 (0) for dipolar (exchange) transitions. To simplify the notation we have suppressed these quantum numbers as well as the symmetrization of the spin states. The rate constants then follow from

$$G_{2(N)2(N) \rightarrow 2(N)1(N)} = \left\langle \frac{2\pi\hbar}{m_H k} \left| S_{2(N)1(N),2(N)2(N)} \right|^2 \right\rangle_{\text{thermal}}$$

Combining the foregoing equations it is easy to find the total rates.

All relaxation processes, except those within the same N dressed-states manifold, are inelastic dipolar transitions. They were calculated previously by Agosta and Silvera. In that calculation cross-terms between bare S-matrix elements were left out. This does not change the order of magnitude. Relaxation processes within the same N-manifold are elastic exchange collisions. We find

$$\begin{aligned} G_{2(N)2(N) \rightarrow 2(N)1(N)} &= \frac{\pi\sqrt{B}\hbar}{m_H \lambda_{\text{th}}} e^{-\hbar\Omega/k_B T} \sin^4\theta \sin^2 2\theta \\ &\quad |(S_{\text{cc,cc}} - S_{\text{trip}})_{k \rightarrow 0}|^2 \\ &= 2.3 \times 10^{-13} \sqrt{T} e^{-\hbar\Omega/k_B T} \sin^4 2\theta_B \sin^4\theta \sin^2 2\theta \text{ cm}^3 \text{ K}^{-1/2} \end{aligned}$$

with $\cotan 2\theta_B = B/0.0569T$, and a similar expression for $G_{2(N)2(N) \rightarrow 1(N)1(N)}$.

1. C.C. Agosta and I.F. Silvera, Contribution to Conference on Spin Polarized Quantum Systems, Torino 1988.
2. A. Lagendijk, I.F. Silvera, and B.J. Verhaar, Phys. Rev. B33, 626 (1986); H.T.C. Stoof, J.M.V.A. Koelman, and B.J. Verhaar, to be published (Phys. Rev. B38).