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광학적 Stern-Gerlach 효과에 있어서 원자도약이 기여하는 영향

The influence of atomic jump in the optical Stern-Gerlach effect

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The mechanical interaction of light and matter has been comprehensively studied since the pioneering work of Kapitza and Dirac in 1933[1)], covering the atomic beam deflection, diffraction, refraction or interference[2)]. One of the interesting issues that came up in the theme of atom-field mechanical interaction is the so-called optical Stern-Gerlach effect (OSGE)[3)]. It has been explored at various levels of sophistication since mid seventies when it was suggested that *the trajectory of a two-state atom interacting with an optical field gradient can be split into two paths*. However, since the theories originally envisaged the OSGE as the coherent processes dealing with an ideal lossless system, we believe it meaningful to explore the effect of the decoherent processes in the OSGE which may be significant particularly in the *optical* frequency regime, which is the goal of this work. For the systems free of damping being only under coherent dynamics, analytic treatments may be available, but for a system open to its environment, analytic approaches may not be always possible. There are a number of theoretical methods in dealing with such open quantum systems, but we will resort to the formalism of the quantum trajectory theory[4)] particularly because the theory provides most direct and intuitive interpretations on the behavior of the system we look into.

Figures 1(a) and (b) show a typical time evolution of a wave packet that has gone through a single atomic jump in the momentum space and in the coordinate space, respectively, where the ratio of the atomic damping rate γ and the atom-field coupling constant g_0 is 0.1, the momentum spread of the initial packet is $10\hbar k$, for an atom initially in the ground state assumed to be *infini-*

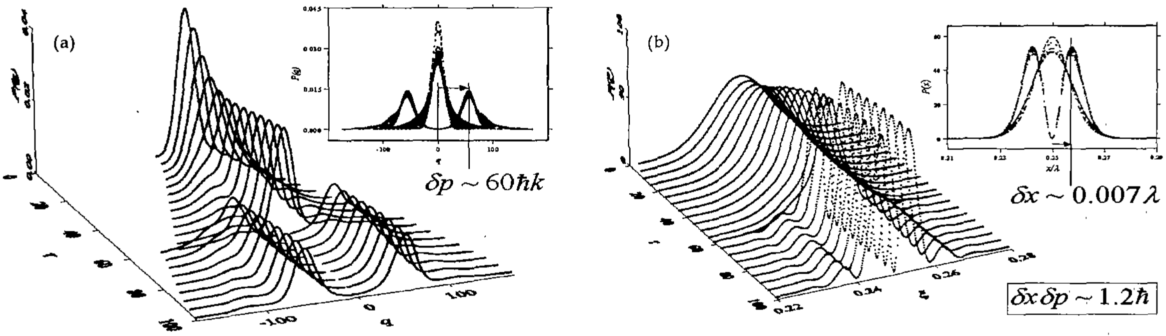

그림 1 The dynamics of an atomic wave packet (a) in the momentum space and (b) in the coordinate space, in which an atomic jump has occurred in the momentum space. for a damped (*infinitely heavy*) atom in the ground state placed at a node. The corresponding wave packet dynamics in the coordinate space. The insets are the ground-level views along the time axis.

tely massive for a conceptual example, and the field in a one-quantum coherent state in a lossless cavity. In the figures, we observe that a drastic change in the atomic wave packet occurs, and it is exactly when an atomic spontaneous emission occurs. We also note that even though the atomic mass was assumed *infinite*, the wave packet does show some "motiom" in the coordinate space. It is thus obviously not a mechanical process, and we found that it is entirely attributed to the intrinsic wave nature of a matter particle as well as to the issue of the position and momentum uncertainty which forms the very heart of the quantum mechanics.

The fact that the atomic damping changes the wave packet in such a radical fashion, one may expect that it can play a significant role in the actual experiments. The actual experimental setup will be most possibly such that a beam of atoms are launched to fly through the cavity mode while the cavity is continuously pumped by an external field, and one measures the position distribution of the atoms emerging from the interaction region landing on a surface at some distance from the cavity system. Figure 3 shows the "far-field" position distributions averaged over 200 atoms detected on a screen located at a large distance from the cavity axis. The thinner line is for the case (a) in which the atoms are assumed to be non-radiative, while the thicker is for the case (b) where the atomic decay channel is open with $\gamma/g_0 = 0.5$. It turns out that during the entire flight time, each atom has gone through about 4.4 jumps on average in case (b). We are observing a few interesting aspects as follows. (1) Even for the atoms and the cavity as strongly damped as the given strengths, the OSGE robustly shows up and has been hardly washed out. (2) The overall width of position distribution in case (a) is greater than the value in case (b). (3) The number of undeflected atoms in case (a) is smaller than that in case (b).

Thus, we conclude that the effect of the atomic damping will show up as these differences in the shape of the position distribution of the detected atoms. Most notably, the width of the position distribution will be generally narrower than that predicted by the ideal theories without the atomic damping taken into account. We will talk about the details in the talk, and draw a statement that the wave packet splitting in the case of an appreciably strong atomic damping is rather due to the discontinuous process, rather than the coherent process which the OSGE was originally envisaged to be.

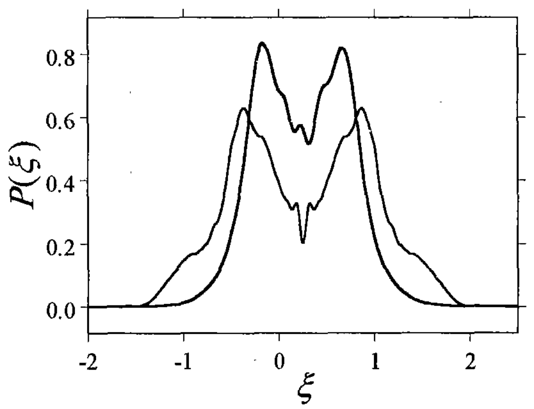

그림 2 The "far-field" position distributions averaged over 200 atoms.

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