Measurement of the coherent optical response of a cold atomic ensemble in the presence of resonant dipole-dipole interactions

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When light scatters on an ensemble of randomly positioned particles, the scattered field has a coherent component, corresponding to its average over many realizations of the random distribution of particles, and an incoherent component, corresponding to the fluctuations of the field around the configuration-averaged field. When the inter-particle distance becomes small in comparison to the wavelength of light, resonant dipole-dipole interactions play an increasing role and modify the way the light is scattered. Using a microscopic and dense atomic cloud, we have for instance recently demonstrated that the incoherent response is no longer proportional to the number of atoms in the presence of interactions, but is rather strongly suppressed. This can be interpreted using a microscopic approach and solving for the time-evolution of the atomic dipoles driven by the external light field as well as the fields scattered by the neighboring dipoles [1].

The near-resonance coherent optical response of cold atomic gases is also modified by dipole-dipole interactions and has been at the focus of recent investigations by several groups, both experimentally [2,3] and theoretically [4,5]. Partly to test the textbook theory of the local-field correction used to describe the coherent optical response of dense atomic media : this theory explains the recently measured cooperative Lamb-shift in hot vapour cells [6] but is predicted to break down when inhomogeneous broadening is absent [5]. Also, one may expect that a dense atomic medium would imprint a large phase shift on the coherently scattered field, a feature of great interest in the context of cold-atom based quantum technologies. Recent experiments performed with single ions, atoms, and molecules have demonstrated in a quite impressive way that single particles can imprint a phase of a few degrees on a laser beam [7,8,9], thus making the observation of a large phase shift induced by a many-body system much wanted.

Here I will present the first observation of a large phase shift (~ 1 rad) imprinted on a laser beam by a dense atomic cloud. This phase shift results from the interference of the incident laser field and the field that is coherently scattered in the direction of propagation of the laser. We measure this phase shift by directly recording the transmission signal on a photodiode in counting mode. In contrast with previous experiments performed with dense atomic media, this large phase shift is associated to a moderate extinction in our case, even at resonance. As in the incoherent case, the saturation of the extinction is a signature of the collective behaviour of the atomic cloud, which has a transverse size smaller than the wavelength of light. Also, the large phase shift is associated to a large group delay (up to -10 ns), which we measure independently by measuring the time resolved coherent response of the atomic cloud to a pulse of light. This corresponds to a very low and negative group velocity (-300 m/s).

References

[1] J. Pellegrino *et al*, Phys. Rev. Lett. **113**, 133602 (2014).
[2] C.C. Kwong *et al*, Phys. Rev. Lett. **113**, 223601 (2014).
[3] K. Kemp *et al*, arXiv:1410.2497 [physics.atom-ph].
[4] J. Javanainen, J Ruostekoski, Y. Li and S.-M. Yoo *et al*, Phys. Rev. Lett. **112**, 113603 (2014).
[5] J. Javanainen and, J Ruostekoski, arXiv:1409.4598 [physics.atom-ph].
[6] J. Keaveney *et al*, Phys. Rev. Lett. **108**, 173601 (2012).
[7] S.A. Aljunid *et al*, Phys. Rev. Lett. **103**, 153601 (2009).
[8] M. Pototschnig *et al*, Phys. Rev. Lett. **107**, 063001 (2011).
[9] A. Jechow *et al*, Phys. Rev. Lett. **110**, 113605 (2013).