Absence of local-field corrections in a homogeneously broadened medium
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We study light propagation by taking atoms to be classical linear dipoles and solving the classical electrodynamics problem exactly, numerically. The results are then averaged over a number of atomic positions compatible with the geometry of the sample. This method may be shown to produce an exact solution to the quantum mechanical problem of light propagation in certain limits, notably low light intensity.

Our specific example is a thin circular disk, analogously to recent experiments [1]. We plot the optical depth as a function of the detuning from resonance in the Figure for several thicknesses of the sample $h$ such that the thickness and the wave number of the exciting light satisfy $hk = 0.25, 0.5, 1$ and 2 (bottom to top). The density of the gas was held constant so that $\rho = 2k^3$, which here means atom numbers ranging from 128 to 1024. The results are averages over a large number (~1000) of random positions of the atoms. The horizontal dashed line shows where the maximum of all absorption lines should be if the venerable Lorentz-Lorenz (LL) local-field shift of the absorption line were valid. In fact, there is no LL shift, and no cooperative Lamb shift either.

FIGURE. Optical depth $D = -\ln T$, where $T$ is the transmission coefficient, for a constant-density disk as a function of detuning $\Delta$ expressed in units of the natural linewidth $\gamma$, for various thicknesses $h$ of the disk with $hk = 0.25, 0.5, 1,$ and 2, from bottom to top. In these computations the radius of the disk is $\sqrt{256/\pi} k^{-1}$, and the density is $\rho = 2k^3$. The dashed vertical line shows where the maximum absorption should be if the Lorentz-Lorenz shift of the resonance line applied.

On the other hand, if we implement a simple model of inhomogeneous broadening by giving the atoms a broad distribution of resonance frequencies, cooperative Lamb shift is seen as in the experiments [1]. It turns out that both the LL shift and cooperative Lamb shifts are mean-field concepts based on the assumption that the polarizability of the atoms is continuously distributed across the sample, and the mean-field approach fails as it ignores correlations that dipole-dipole interactions establish between nearby radiators. Inhomogeneous broadening validates mean-field theory by suppressing the correlations, but in a homogeneously broadened sample the century-plus old concepts of local-field corrections fail in a spectacular fashion.