Abstract

Spontaneous emission arises due to the interaction of the atom with the electromagnetic field. Hence, it is not completely intrinsic to the atom, but also depends on its electromagnetic environment. By controlling the local density of states (LDOS) it is possible to enhance or decrease the rate of spontaneous emission. The figure of merit for enhancement or decrease in the spontaneous emission rate is the Purcell factor. In this thesis we analyze the effect of the electromagnetic modes on the Purcell factor. Conventional experiments to measure the Purcell factor involve characterizing the change in decay rates of atoms or fluorescent molecules. Recent research has shown that in the weak-coupling regime, Purcell factor is analogous to the modification of antenna impedance. The ability to probe the Purcell factor with antennas, expands the scope of measurements from optical frequencies to microwave frequencies.

In this thesis we have used this antenna impedance approach to measure the electric and magnetic Purcell factor for a fishnet metamaterial structure designed for operation in the microwave frequency range 5-15 GHz. The metamaterial, due to its hyperbolic dispersion in the TM_z polarization, has a large local density of states which enhances the Purcell factor. At the same time, lack of propagating modes in the TE_z polarization suppresses the Purcell factor. We demonstrate experimentally, that it is possible to resolve this polarization dependent Purcell factor at microwave frequencies using antennas.

In the second part of the thesis, we focus on how the electromagnetic modes modify resonance energy transfer mediated by dipole-dipole interactions (DDI). Resonance energy transfer is the process of exchange of excitation from an atom in an excited state (donor) to an atom in a ground state (acceptor). Of particular interest is the regime when the donor-acceptor separation distance is subwavelength. At such distances the energy transfer is due to near-field, non-radiative mechanisms. Such transfer of excitation governs important phenomena such as Förster resonance energy transfer (FRET), responsible for energy transfer between molecules at nanometer distances.

We show that, as for spontaneous emission, a classical analogue to resonance energy transfer with antennas can be formulated. We demonstrate that resonance energy transfer can be studied through the mutual impedance (Z_{21}) of two linear circuits coupled with subwavelength antennas. We develop classical analogues to characterize the influence of electromagnetic modes on processes mediated by DDI like FRET in terms of the mutual impedance (Z_{21}) of a two-port microwave network. I measure resonance energy transfer in vacuum at the frequency 1 GHz where the characteristic FRET like r_{DA}^{-6} dependence is reported, r_{DA} being the donor-acceptor separation distance. We measure the change in resonance energy transfer inside a parallel plate waveguide and compare with theoretical predictions. This work will contribute towards developing a coherent understanding the effect of the electromagnetic environment on processes mediated by dipolar atom-field interactions.