What is an optical cavity mode? This remarkably simple concept has a wide range of answers in the literature, especially when one carefully considers material and photon losses. I will attempt to answer this “simple” question in terms of so-called quasinormal modes (divergent modes of all open cavity systems), showing how one can introduce a rigorous modal theory of light-matter interactions and the Purcell effect for quantum dots (QDs) and artificial atoms coupled to a wide range of complex nanophotonic structures. As an application of the theory, I will show how to understand QDs coupled to metal resonators, hybrid systems of metal resonators and photonic crystal cavities, and even hyperbolic metamaterial resonators.

For the second part of the talk, I will consider QDs embedded in semiconductor cavity structures, and describe some of our result work on polaron master equations, where electron-phonon interactions are treated microscopically. I then apply this approach to the biexciton-cascade system, and explore a method of coherently and deterministically exciting a QD coupled to a cavity which produces photons with simultaneously high efficiency and indistinguishability with orthogonal polarization to all input fields. I show how this cavity-assisted adiabatic passage single-photon source can produce photons with simultaneously over 90% efficiency and indistinguishability, using realistic experimental parameters.

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