

5 Quantum Dots: Spectroscopy of Artificial Atoms

5.1 Introduction

Semiconductor quantum dots are fascinating objects, since, in some respect, they can be regarded as artificial atoms [1]. Figure 5.1 shows a very schematic comparison of a real three-dimensional atom and a disc-shaped quantum dot. The structure of real atoms is three-dimensional, while most of the artificial quantum dots can be regarded as large Q2D atoms, since the lateral dimensions are in most cases much larger than the vertical extension. Of course, a crucial difference between the two systems is the shape of the confining potentials, which, for real atoms is essentially the Coulomb potential of the nucleus, and, for quantum-dot atoms in some approximation a two-dimensional parabolic potential. In Fig. 5.2, the resulting energy-level structures for a Hydrogen atom and a quantum dot, containing a single electron, are displayed schematically. Due to the reduced symmetry of the disc-shaped dot, the degeneracy of the energy levels is smaller than in the

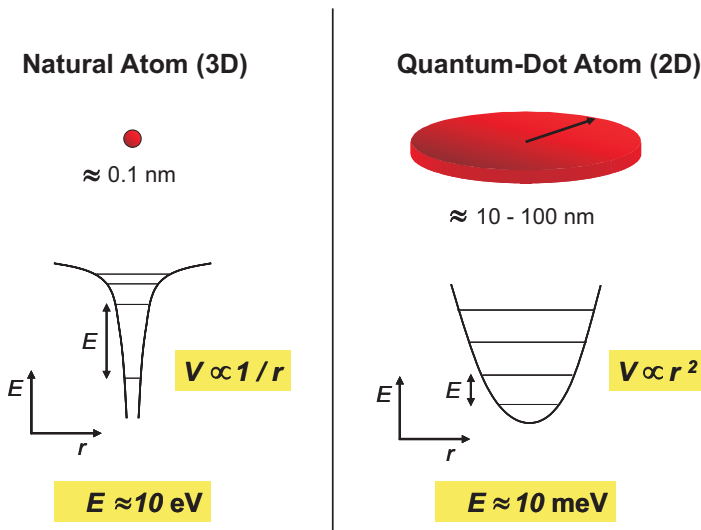


Fig. 5.1. Schematic comparison of a real atom (*left*) and a quantum-dot atom (*right*) represented by a disc-shaped two-dimensional quantum dot

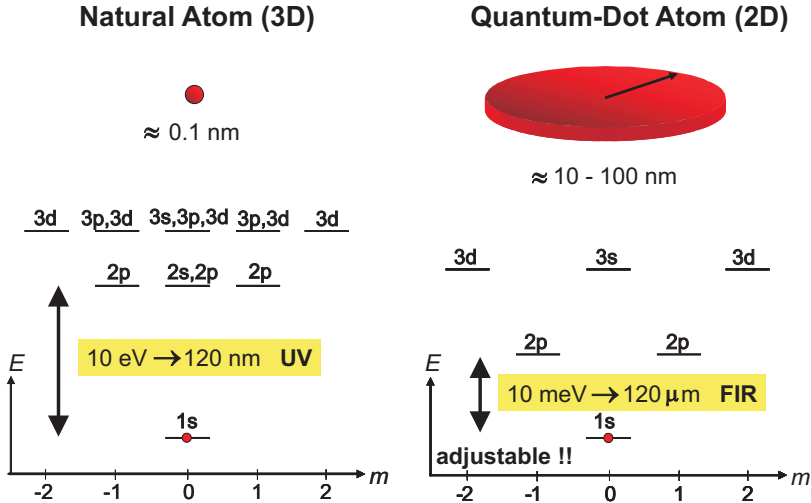


Fig. 5.2. Schematic comparison of the energy-level structure of a Hydrogen atom (*left*) with a quantum-dot Hydrogen atom, i.e., a quantum dot containing a single electron

three-dimensional case. The most striking difference, however, is that in a semiconductor quantum dot, both, the level structure and the order number, i.e., the number of electrons in the quasiatom, is tunable to some extent. Furthermore, the quantization energy is in a quantum dot of the same order of magnitude as the electron-electron Coulomb interaction, in contrast to real atoms, where the quantization is typically much larger. From this one can expect in quantum dots an interesting interplay between quantization- and Coulomb interaction-induced effects, as will be discussed later.

In this chapter we will see that in these well-defined quantum-mechanical structures, e.g., parity selection rules for inelastic light scattering and the exclusion principle between far-infrared (FIR) and inelastic light scattering spectroscopy, as generally discussed in the first part of this book, can be nicely studied. Historically, electronic excitations in lithographically-defined quantum dots were studied first by FIR transmission spectroscopy, starting in 1988 [2, 3, 4, 5, 6, 7, 8]. In the following years, also resonant Raman scattering, i.e., inelastic light scattering, was successfully applied to study the spectrum of elementary excitations of these systems [9, 10, 11, 12, 13]. As introduced in the first part, for quantum wells it is well known that besides collective spin-density (SDE) and charge-density excitations (CDE) one can observe nearly unrenormalized excitations – so called single-particle excitations (SPE) – in inelastic light scattering experiments. Both, SDE and CDE are collective excitations, where SDE are affected by exchange interaction and CDE by the full Coulomb interaction of the electrons. However, the origin of the SPE's, which seem to be unaffected by the particle-particle interaction, has posed