Exploring the Quantum World: A Journey Through Double Quantum Dots

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Science seems to be a subject that most students in school dread. Of course, there are those who enjoy science and maybe even pursue a career in it. Nonetheless, when it comes to quantum physics everyone seems intrigued. There is something about the concept of uncertainty and the mystery around this subject that fascinates physicists and others alike. At the smallest scale, our classical understanding of the laws that govern nature breaks down, and all we are left with are probabilities and uncertainty.

The focus of this bachelor's project lies on an interesting nanosystem consisting of a double quantum dot (DQD) coupled to a microwave resonator. This might sound complex, but we can break it down for simplicity. Imagine two curved mirrors, that trap any light that they capture. A DQD between these two mirrors can be said to be *resonator-coupled*.
The star of the system is the double quantum dot, which is simply two quantum dots (QDs) in series. But what is a quantum dot?
In simple terms, a quantum dot is something like a small crystal or region in space, where an electron can only occupy certain discrete energy levels, this might be reminiscent of an atom, QDs are in fact often referred to as *artificial atoms*. So why do we bother with these QDs instead of just sticking to atoms? Well, since QDs are engineered and not just found in nature, one can adjust their inherent energy levels as one sees fit. This makes QDs extremely versatile and useful in a lot of different applications.
Having two dots connected in series one can engineer an energy gap between the discrete levels from one to the other, which makes an electron lose energy jumping between them, which in quantum physics often translates to emitting photons.

In this project, we investigate the mathematical dynamics of the DQD system to calculate electron currents flowing through the dot.
The rate at which photons are emitted from the DQD and 'collected' by the resonator is also interesting and can be found mathematically.

This system and the work done in this thesis might appear quite abstract and not very useful in real life. But depending on the setup, the system can serve as a single photon source or detector. This can have a variety of interesting applications in the modern world. Quantum cryptography and photon signal transmissions are the most intuitive applications of these effects. Quantum cryptography for instance could be a game changer when it comes to secure, fast, and reliable communication.

Of course, this technology does not come without its challenges.
As was briefly mentioned, the system at hand deals with microwaves, which like visible light are electromagnetic waves, only with much lower energy. Creating single photons at any energy is not an easy feat, achieving this at low energy scales makes it much more challenging. For this system to work as it does, the whole setup is cooled down to temperatures just above absolute zero, which for clarity is $-273.15°C$. This of course is not very convenient for commercial use.
Further research on these nanosystems might help make them more practical in the future, even so, concepts and results found by studying these systems are sure to provide valuable insights and applications across various scientific disciplines.