Quantum Tunneling

Write-Up for "Your passion for (AMO-) physics: What are you curious about?" organized by Prof. Dr. Thomas Pfeifer.

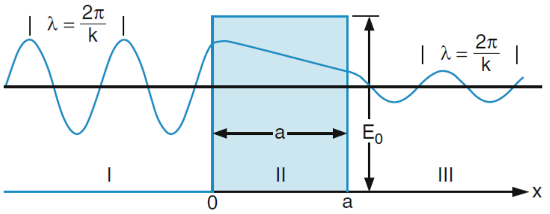
First Observations

Quantum tunneling (QT) was first observed in the late 18th and early 19th century through alpha decay and unexpected conduction regimes in gases and later in a vacuum.[3, 4] People at the time did not know that they were observing a tunneling effect.

Description

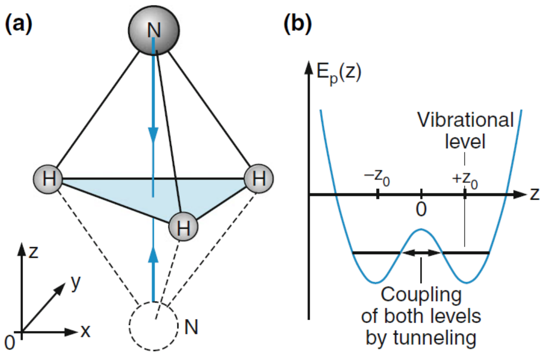
After the discovery of the Schrödinger Equation in 1925/26, it did not take long to describe QT precisely.[5]

In 1928, George Gamow was the first to explain alpha decay using the Schrödinger Equation.[7] He used a box potential approach to approximate the potential landscape around a nucleus. He explicitly showed that the Schrödinger wave function could penetrate into regions that are classically forbidden. This way, a particle can tunnel through potential barriers.[10]



Naively we could imagine a macroscopic QT effect. Due to the size and energy scale of the effect, macroscopic tunneling like a fly through an insect net will not happen in the lifetime of this universe.

A year earlier in 1926/27, Friedrich Hund already described the vibrational modes of molecules using QT.[8] He proposed, among other things that in a symmetric molecule such as ammonia, the single nitrogen atom can tunnel through the potential barrier of hydrogen atoms and in this way occupy both energetically equal positions.



It is possible to describe such arrangements as two-state systems.[10, 12, 13] These systems can have a dipole moment and therefore interact with external EM-fields. For Hund, this resulted in spectral lines in certain molecules that he could correctly predict.

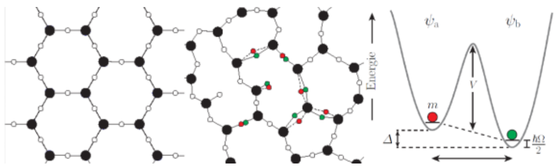
QT and its Applications

A long time has passed and today QT is used in a wide field of science and technology.[9] Technical applications such as the scanning tunneling microscope or the flash memory[17] utilize QT to see or feel surfaces on the atomic scale or memorize big amounts of data.

Also in chemistry or biology, the QT effect is used to describe chemical reactions or mechanisms such as DNA-mutations or photosynthesis.[15, 16]

QT Systems in Amorphous Solids

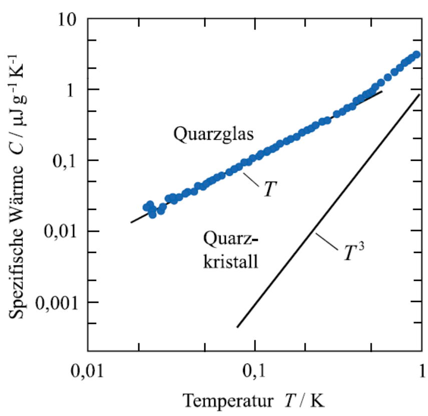
In the Debye model, we can observe a T^3 temperature dependence of the heat capacity of crystalline solids at low temperatures.[18] It is surprising that amorphous solids with the same composition of atoms but a different structure show a linear dependence. To describe this discrepancy we must have a closer look on the atomic level.



We can imagine tunneling systems in amorphous solids (glasses) in which particles can occupy energetically similar states. This coupling can form new energy eigenstates that will contribute to the heat capacity.

We can safely assume that the density of states is approximately temperature independent.[18]

By calculating the internal energy and the specific heat of glasses, we see the measurable linear temperature dependence.



This shows us that microscopic QT can also have macroscopic effects in areas where we would not expect it at first glance.

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