

## 3.5 Why does a quantum mechanical state change?

Since all Eigenstates of the Hamiltonian are stable, one needs at least a short perturbation of the system to get an excited state; e.g.:

- A beam of
  - electrons
  - electromagnetic radiation
  - positrons
  - neutrons
  - ...
- The scattering may be elastic or inelastic, i.e. momentum and/or energy may be exchanged.
- Electrons can be scattered by core electrons
- There exists an interaction between electrons and phonons
- The thermal energy of the system itself causes an excited state since only at  $T = 0$  the Fermi energy describes the highest occupied energy state. We find a dynamic equilibrium between states steadily increasing or decreasing the energy.
- Surfaces and defects in a crystal change the Hamiltonian of the perfect solid leading to additional electronic transitions.

For all these processes according to Eq. (3.18) the transfer matrix element can be calculated; they quantize the probability for these transitions.

The excited state may lose energy by the same processes as described above:

- by electromagnetic radiation
- the same particles, which moved into the solid, lose energy and momentum and will be detected in the scattered beam.
- thermal processes (e.g. phonons)
- at defects
- on surfaces

REMARK: Principally you do not need superconductivity to find zero ohmic resistance; once a current flow started (described by the  $k$ -distribution of electrons, which are Eigenstates of the Hamiltonian) it would be stable for infinite time. You need defects within the crystal or phonons to reduce the current by scattering.

***For every well defined measurement and if knowing the underlying processes, quantum mechanics provides the adequate calculation rule.***

1. Which is the starting state?
2. Which is the end state?
3. Which expectation value do I have to calculate?

Examples:

Scattering experiment:

1. incoming free particle
2. outgoing free particle
3. Scattering cross section

Recombination processes:

1. State in the first band
2. State in the second band
3. Cross section of a trap (a surface)/Probability for a radiative transition
  - This allows to calculate which processes have the highest transition probability
  - Often approximation methods are used to calculate matrix elements
  - Essential for all calculations is the Hamiltonian of the perfect system, i.e. the Eigenvalues and Eigenvectors. Quantum mechanical Hamiltonians almost always look like:

$$H = \sum_i E_i |f_i\rangle \langle f_i| \quad (3.21)$$