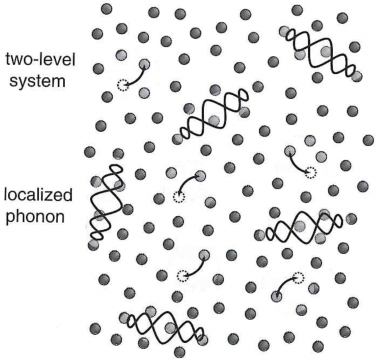
Electronic effects in discorded systems

Weak localization and conductivityat low temperatures; interpretation of the experimental conductivity trendasafunction ofthe magnetic field

July 1, 2021

Frame Title



- Phonons with wavelength shorter than the mean distance between two impurities get trapped and localized, scattering back and forth between two impurities

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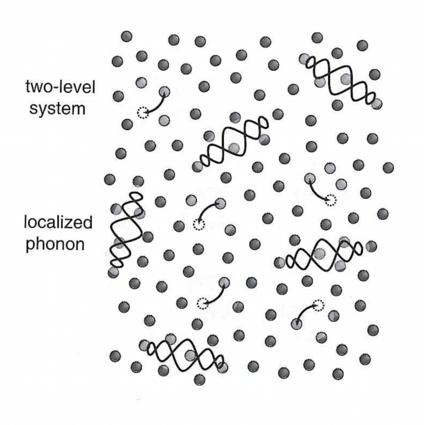

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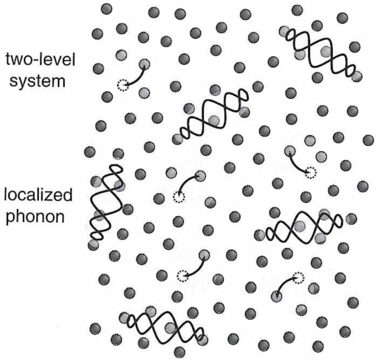

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- For each atom there is a probability to move to the next one and a probability to return back to the previous one

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- This will affect the electrical conductivity.

Band conduction as an interference effect

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- This is perhaps easiest to see in a tight binding model where the Hamiltonian explicitly contain terms which corresponds to jumps between neighbouring atoms like:

$$H = E\sum_n |n\rangle\langle n| + T\sum_n (|n\rangle\langle n+1| + |n+1\rangle\langle n|)$$

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where T is the transmission coefficient (Tunnel amplitude).
- Solving the time-Independent Schrödinger $H|\psi >= \hbar\omega|\psi >$ equation we yields with the dispersion relation:
$$\omega_k = \frac{2T}{\hbar} \cos ka$$

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- In a crystal the probability for an electron to jump to another atom is independent of the considered atom in the chain.
- If the perfect symmetry of the crystal lattice is destroyed, the interference pattern is lost, and it is not easy to guess what will happen. The answer is localization: The electrons will not propagate far from the starting point.

Weak localization

- There is one situation where the analysis of the interference pattern of all the possible alternative paths is simplified. This is when the probability to return to the same site is small, so repeated returns can be ignored. This is far from the insulating state, and only is seen as a small reduction in the conductivity, hence the name weak localization

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- This will be a good approximation if the mean free path,Λ is much larger than the Fermi wavelength, λ_F .

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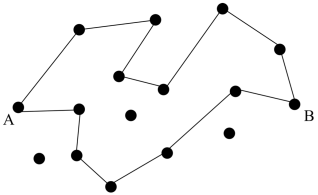

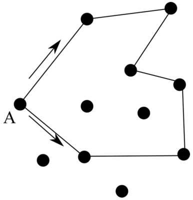

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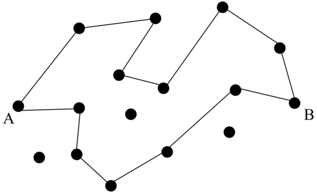

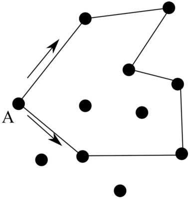

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- The probability is then:

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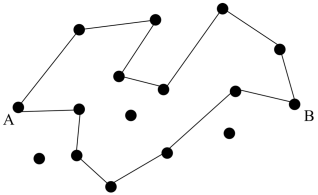
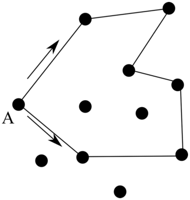
$$= \sum_i |A_i|^2 + \sum_{i\neq j} A_i A_j^* e^{i\left(S_i - S_j\right)}$$





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- The terms in the second sum will then average to zero because of their randomly distributed phases. Thus, we are left with independent contributions from each path and no interference.

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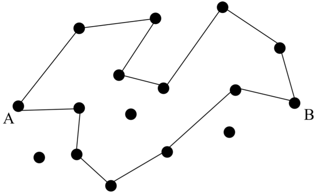

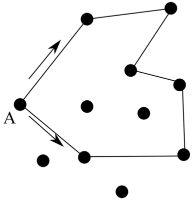

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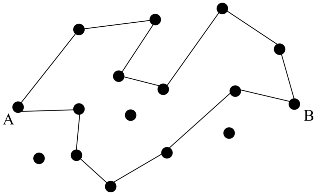

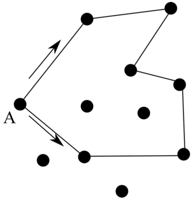

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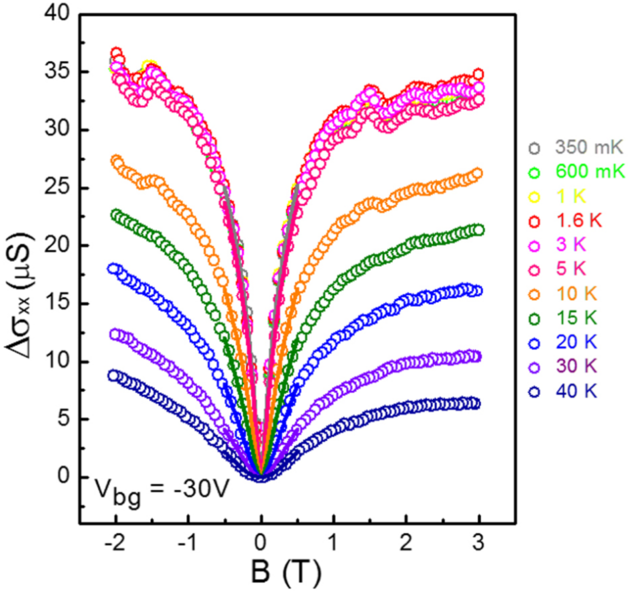
- To each geometrical closed path there will correspond two quantum paths (clockwise and counterclockwise directions) As long as time reversal symmetry is not broken these will have the same amplitude and the same phase. This means that the two path interfere constructively, so the electrons will move less than expected classically, this will reduce the conductivity.


40
35
30
25
20
15
10
5
0
$\Delta\sigma_{xx}$ (μS)
-2
-1
0
1
2
3
B (T)
V_{bg} = -30V
350 mK
600 mK
1 K
1.6 K
3 K
5 K
10 K
15 K
20 K
30 K
40 K

electrical conductivity

- However, if an electron runs across a closed path, and there is a magnetic field, the electron gain a phase (Berry phase , look at Aharonov-Bohm effect). Taking into account this phase we expect the quantum correction to vanish, and the classical conductivity to be restored.
- All curves show that the conductivity increases when a magnetic field is applied because the weak localization is removed.
- The effect is more pronounced at low temperatures. This is because at higher temperatures, the thermal motion of the defects will give random phase changes to the electron waves, and thereby reduce or destroy the phase correlation between the two directions of transversing a loop. Quantum intereference is lost by dephasing, and weak localization disappears.
- When the B increase (in modulus) the electrons gain the berry phase, and the quantum correction disappear.
- The interference term acquires a phase that bring the average to zero when all paths are taken into account. Thus, we expect the quantum correction to vanish, and the classical conductivity to be restored.