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Research project: ""Currents in nonsuperconducting nanorings"

Time–dependent manipulation of quantum states in nanosystems is an important problem directly related to future applications both in the context of quantum control and the reduction of decoherence. There is a natural ground for implementing such ideas: mesoscopics and nanoscopics where quantum effects play a crucial role. Unfortunately, analysis of quantum systems affected by external time–dependent forces and/or fields $F(t)$ is extremely difficult and only very few models are exactly solvable.

We studied currents in a one–dimensional quantum systems of ring topology threaded by a time–dependent magnetic flux $\phi = \phi(t)$ generated by a magnetic field $B = B(t)$. If the magnetic field is perpendicular to the ring, a variety of Aharonov-Bohm effects can be observed. As an example one can mention persistent currents which, in the case of a static magnetic field B, oscillate as a function of the flux ϕ. We know from literature that when the magnetic flux changes linearly with time, $\phi(t) = A\,t$, the induced electromotive force $E \propto d\phi(t)/dt = A$ is time-independent and electrons move in a static electric field. This case is interesting because it is similar to a system of electrons moving in a periodic lattice under the influence of a dc voltage. In the regime of small values of A the induced currents display Bloch oscillations and the time-averaged current is zero. In turn, for large values of A the induced currents may display a dc component. The last example we want to mention is a current driven by a periodic magnetic flux $\phi(t) = \phi_{dc} + \phi_{ac}\cos(\omega t)$. In this case, a dc persistent current is of the same order as in the static magnetic field and the oscillating current is very small containing in its Fourier spectrum a significant contribution from only a small number of frequencies.

We have proposed another scheme involving variation of the magnetic flux to manipulate currents: the magnetic field perpendicular to the ring is changed from its initial constant value $B(t_1)$ to the final constant value $B(t_2)$. The corresponding magnetic flux is changed from the initial constant value $\phi(t) = \phi(t_1) = \phi_1$ for time $t \leq t_1$ to the final constant value $\phi(t) = \phi(t_2) = \phi_2$ for $t \geq t_2$. Dynamics of electrons moving in the ring is described by the Hubbard and the extended Hubbard models. We have analyzed how the induced currents depend on the rate of flux variation $\dot{\phi} = (\phi_2 - \phi_1)/(t_2 - t_1)$. We have found that for zero and infinitely strong many–body interactions the resulting current has the following properties: for $t > t_2$ it is independent of $\phi(t)$ for $t_1 < t < t_2$, i.e., the resulting current is independent of the way the magnetic flux is modified/switched on; solution of the equilibrium problem at $t = t_1$ and the value of ϕ_2 entirely determine the current for $t \geq t_2$. For intermediate values of the interaction strength we have carried out numerical calculations and pointed out that the current displays regular or irregular time-oscillations and the amplitude of oscillations is sensitive to the rate of the flux changing $\dot{\phi}$: slow changes of the flux result in small amplitudes of the current oscillations and *vice versa*. We conclude that in some regimes the currents can be controlled by the rate of flux variation $\dot{\phi}$.

On the one hand, experimental observations of the current may give important insight into various properties of the system, as e.g. the spin–charge separation. On the other hand, one can induce an oscillating current of desired amplitude and frequency, which time-average is non-zero and contains a dc component. The significant advantage of the method based on the flux variation is the 'noninvasive' manipulation performed outside the ring, without coupling to external leads. Recent progress in the highly controlled fabrication of quantum ring structures makes the verification of our findings quite realistic in the nearest future.

Our analysis can be applied either to mesoscopic rings or to rings built in the optical lattice setup. The difference in energy scales in both systems shows up mainly in different time scales of the external driving.

We intend to publish a paper on the above mentioned findings.