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Magnetic edge states in transition metal dichalcogenide monolayers

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Magnetic edge states (MES) in a 2D system are quite similar to the magnetic surface states (MSS) in a bulk specimen discovered experimentally in 1960 by Khaikin [1, 2] and theoretically described by Nee and Prange [3–5]. Both those and others are formed by the so called "skipping orbits" of electrons: some electrons cannot close their orbits in the magnetic field because center of the Larmour precession lies too close to the surface or even beyond the specimen. In the last case the classically allowed for electrons area lies between a branch of "magnetic parabola" and the specimen boundary. Then the separation between turning points can be significantly less than the corresponding parameter of the bulk electrons and that's why the MSS energy quanta exceed the Landau quantization intervals. As a result the Landau levels in the bulk can be already blurred by temperature and disorder while MSS are still observable in resonant experiments. That's how MSS were observed by Khaikin when he measured the surface impedance of metals at very weak magnetic fields. The Nee and Prange theory was developed for weak fields either.

In the present paper we propose the theory of MESs for conventional 2D semiconductor systems (like GaAs quantum wells) and for monolayers of transition metal dichalcogenides (TMDC) at arbitrary strong magnetic fields. Effect of the monolayer boundary, e.g., edge of a half-plane, results in lifting the degeneracy. The Landau levels turn into 1D subbands in which energy depends on the component of electron momentum parallel to the edge of the half-plane. Optical interband magnetoabsorption of the conventional semiconductors is governed by the same selection rule for the Landau level number that acts in case of unbounded plane $\Delta n = 0$ of the spectrum in position of the oscillator suspension point. The van Hove singularity of the M_0 type (threshold of absorption) remains square root behavior but the coefficient at $1/\sqrt{\omega - \omega_{\min}}$ is anomalously large if the specimen width is much larger than the magnetic length.

More complicate situation occurs for a half-plane of TMDC monolayer. As it is known in this case the Landau levels for unbounded plane are additionally twofold degenerate in the valley index τ. Presence of an edge lifts this degeneracy either: τ-doubling arises as one can see in Fig. 1, where Δ is the forbidden gap width, ω_c is the cyclotron frequency, X is the suspension point position and l is the magnetic length.

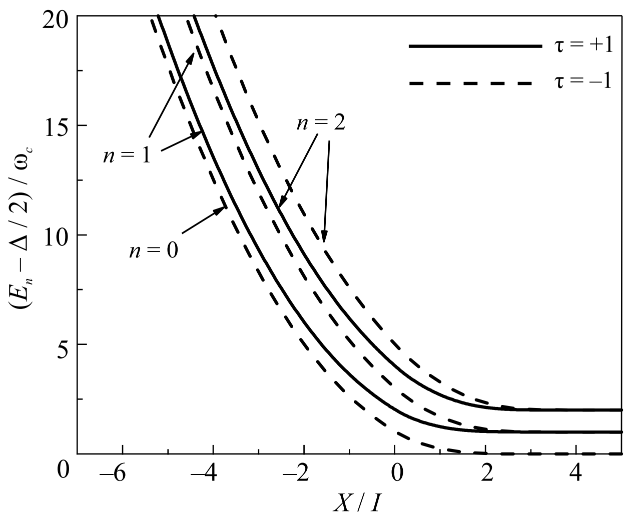

Fig. 1. Landau subbands for MoS_2 in the conduction band at the magnetic field 10 T

Unlike conventional semiconductors the selection rule $\Delta n = 0$ is violated for a semi-infinite TMDC monolayer and, strictly speaking, any interband transition is allowed though intensity of the forbidden in the unbounded plane transitions is much less than for allowed ones. For suspension points both inside and outside the specimen at distances from the edge much greater than the magnetic length analytical formulae for the 1D subbands dispersion law are obtained; in the intermediate region numerical calculations have been made.

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