Nematic Ordering at the (111) Surface of Bi in the Quantum Hall Regime

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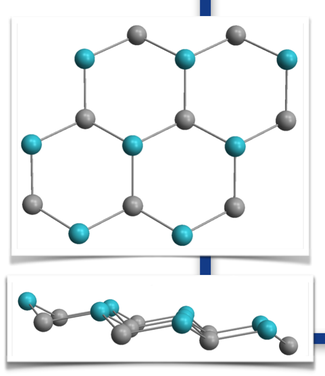
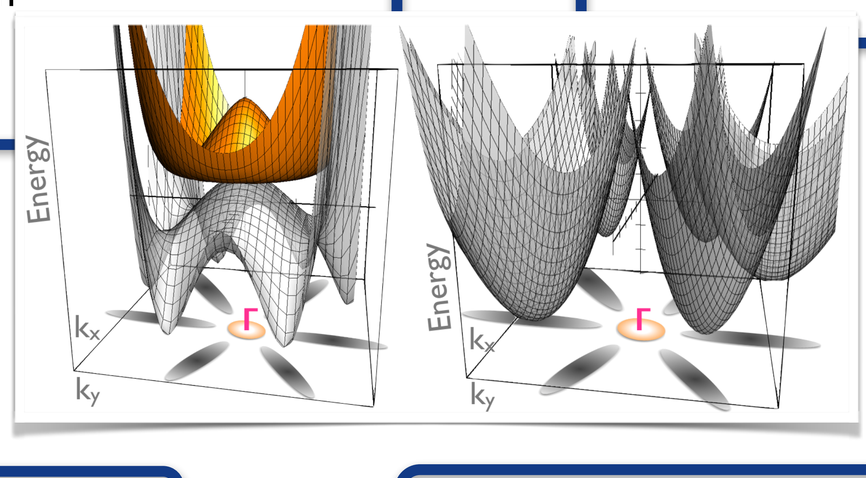
Abstract

The (111) surface of bismuth exhibits six degenerate anisotropic valleys of approximately elliptic shape. In multi-valley systems with anisotropic valleys it has been conjectured that unusual states with nematic ordering may be formed [2,3]. Within a Hartree-Fock mean field treatment we theoretically investigate the ground states of the Bi(111) surface in the quantum Hall regime at different filling factors. We explicitly study the competition of intra- and inter-valley scattering processes as well as the effect of local strain.

The System: (111) Surface of Elemental Bi



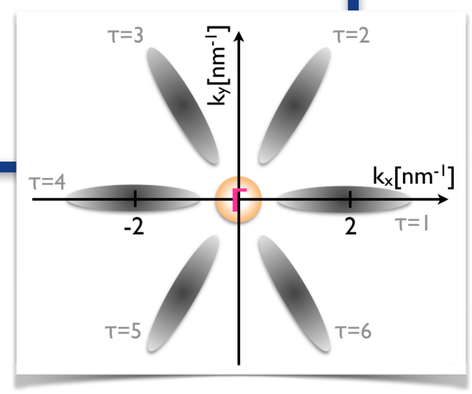
- Two-dimensional surface states
- Band structure with six anisotropic valleys arranged around the Γ point
- Experimental observation of anisotropic Quantum Hall states [1]



Left: Sketch of the dispersion of the Bi(111) surface states

The Model: Six Elliptical Valleys

- Six valleys $\tau \in \{1,..,6\}$, modelled as ellipses
- Effect of local strain: lowers the energy of the two valleys along the strain axis [1]



Right: Model of the band structure as 6 elliptical valleys

The Leading Question

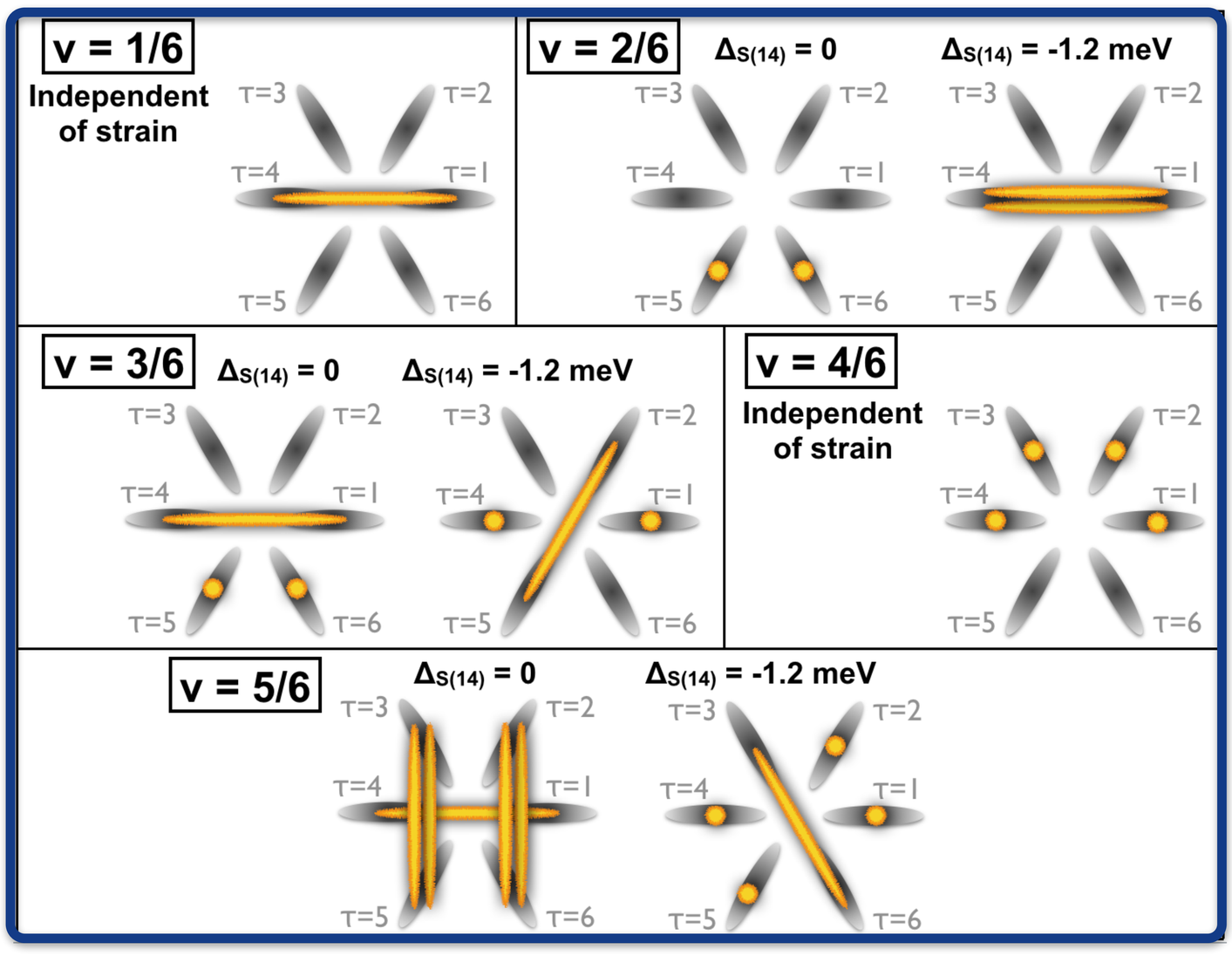
- In the Quantum Hall regime, for different filling factors v:

Valley ordering of the ground state ?

Theoretical Treatment

- Anisotropic Landau Level quantisation within each valley [2]
- Coulomb interaction: Inter-valley and Intra-valley scattering $H_C = H_{C,inter} + H_{C,intra}$
- Local strain: $H_s = \Delta_s \sum_\tau (\delta_{\tau,1} + \delta_{\tau,4})\, c_\tau^\dagger c_\tau$
- Hartree-Fock treatment of $H = H_C + H_s$

Preliminary Results



Conclusions

- Nematic phases at all filling factors v
- Strain influences ground state phases
- Inter-valley processes do not play a role at reasonable values of B
- For perfectly elliptic valleys: degeneracy between opposite valleys

Open Questions

- Hartree Fock does not decide between opposite, perfectly identical valleys → degeneracy [3]
- What might lift this degeneracy ?
  - →Deformation of the valleys?
  - →Fluctuations beyond Hartree Fock?

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References

[1] B. E. Feldman, A. H. MacDonald, A. Yazdani, et al, Science Vol. 354, 6310, pp. 316-321 (2016)
[2] X. Li, Fan Zhang, and A. H. MacDonald PRL 116, 026803 (2016)
[3] I. Sodemann, Z. Zhu, L. Fu, arXiv:1701.07836