Non-conservation of the valley density and its implications for the observation of the valley Hall effect

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In the absence of intervalley scattering valley number is believed to be a good quantum number with an associated valley Hall effect. This can be detected through the observation of non-local resistance [1] or through Kerr rotation microscopy [2] since valley number can also be identified with a certain value of orbital magnetization. However, we show that the conservation of the valley density in a multi-valley insulator is broken in an unexpected way by an electric field, such as the one that is used to drive the valley Hall effect. This observation explains how a fully gapped insulator (i.e., one without edge states that cross the Fermi level) can support a valley Hall current in the bulk and yet show no valley density accumulation at the edges. If the insulator is not fully gapped (either because there are edge states crossing the Fermi level or because carriers are introduced in the conduction or valence band) then valley density accumulation at the edges is possible, paving the way to a direct observation of the valley Hall effect. However, the accumulation has no contribution from undergap states and can be expressed as a Fermi surface average, whose value strongly depends on the form of the electronic wave functions near the edge of the system (see Fig. 1).

References

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[2] K. F. Mak, K. L. McGill, J. Park, and P. L. McEuen, Science 344 (2014) 1489

Figures

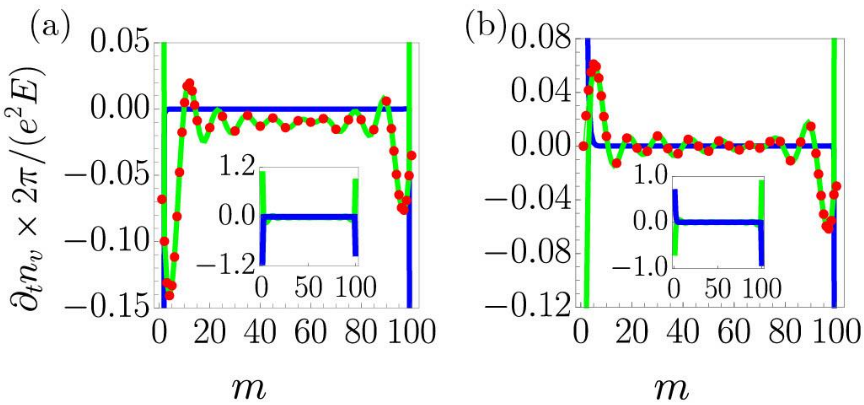

Figure 1: Panel (a) Valley density accumulation rate in a doped graphene monolayer nanoribbon with zig-zag edges due to the valley Hall current (green line), the non-conservation term (blue line) and the combined effect of the two (red dotted line). Panel (b) Same for a nanoribbon with one edge zig-zag and the other bearded. The full range of the green and blue curves is shown in the insets. Label *m* marks position across the ribbon measured in units of √3/2 *a*, where *a* is the graphene lattice constant. The gap size is 0.2*t* and the Fermi energy is 0.3*t*, where *t* is the nearest neighbor hopping.