DAy 4 (26 June): 14:50 – 15:30

Disorder effects on 3-dimensional Z_2 spin Hall insulators / chiral metals

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3-dimensional Z_2 quantum spin Hall insulator (QSHI), originally proposed by Fu, Kane and Mele, supports a spin-selective edge state, forming a Dirac-cone like energy dispersion at its 2-dimensional surface boundary. Having no "$U(1)$ counterpart" into which this 3-d Z_2 QSHI can be adiabatically connected, this electronic phase is currently regarded as a new state of matter which goes beyond the quantum Hall paradigm (namely, c.f. 2-d Z_2 QSHI). In this note, we have studied the disorder effect (non-magnetic impurities) on this peculiar electronic phase, mainly focusing on the quantum critical point between the Z_2 QSHI and trivial band insulator;

$$\mathcal{H} \equiv \int dr \psi^{\dagger}(r) \big\{ \mu \hat{1} + \hat{\gamma}_{\mu}(-i\partial_{\mu}) + m\hat{\gamma}_5 \big\} \psi(r),$$
$$\hat{\gamma}_1 \equiv \sigma_y \otimes 1, \quad \hat{\gamma}_2 \equiv \sigma_z \otimes s_x, \quad \hat{\gamma}_3 \equiv \sigma_z \otimes s_y, \quad \hat{\gamma}_5 \equiv \sigma_x \otimes 1,$$

where a finite mass term m induces the phase transition between the nontrivial insulator and trivial one. Taking into account various type of "on-site" impurities, we first derive the phase diagram spanned by the mass-term m, chemical potential μ and strength of the disorder within the self-consistent Born approximation. Thereby, we found a *finite* density of state even at the zero-energy *and* at the phase transition point, i.e. $m = \mu = 0$, if the strength of the disorder potential exceeds some critical value. To uncover whether this bundle of states registered at the zero-energy are extended or localized, we next derive the self-consistent equation for the current relaxation kernel (i.e. inverse of the diffusion constant), only to discuss about the *number* of mobility edges and the criticality around them within the mode-mode coupling theory framework.