Quantum Spin Hall edges and the proximity effect

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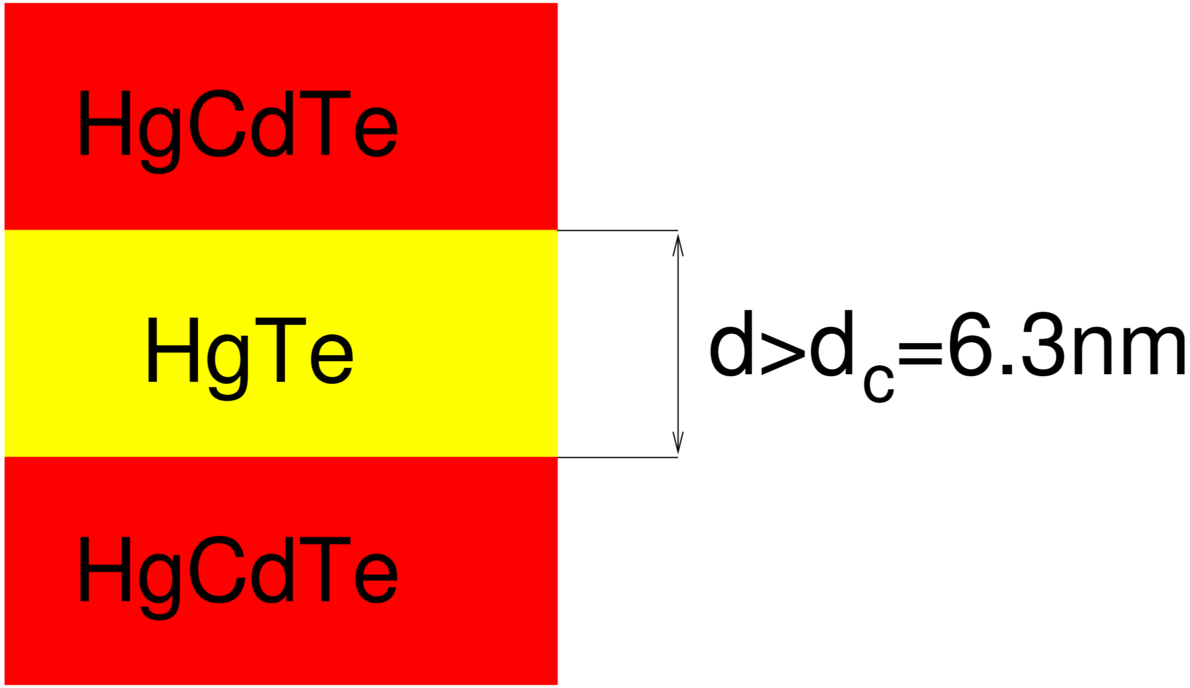
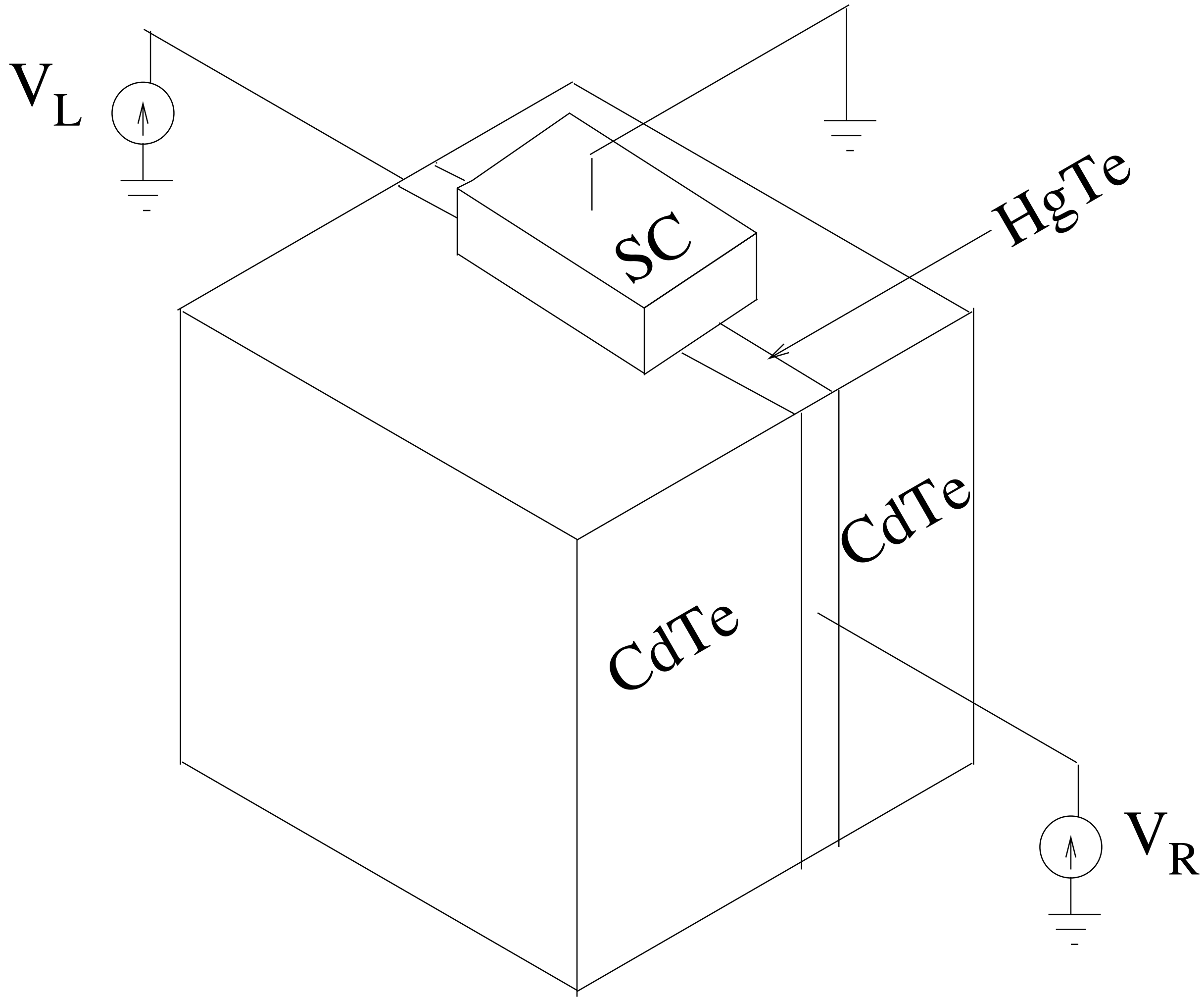
Quantum Spin Hall edges

Quantum wells CdTe/HgTe with bulk gap 30 meV and counterpropagating edge modes.



$$H_0 = -i\hbar v_F \sum_{\sigma=\pm 1} \sigma \int dx \psi^\dagger_\sigma \partial_x \psi_\sigma$$

Superconducting barrier



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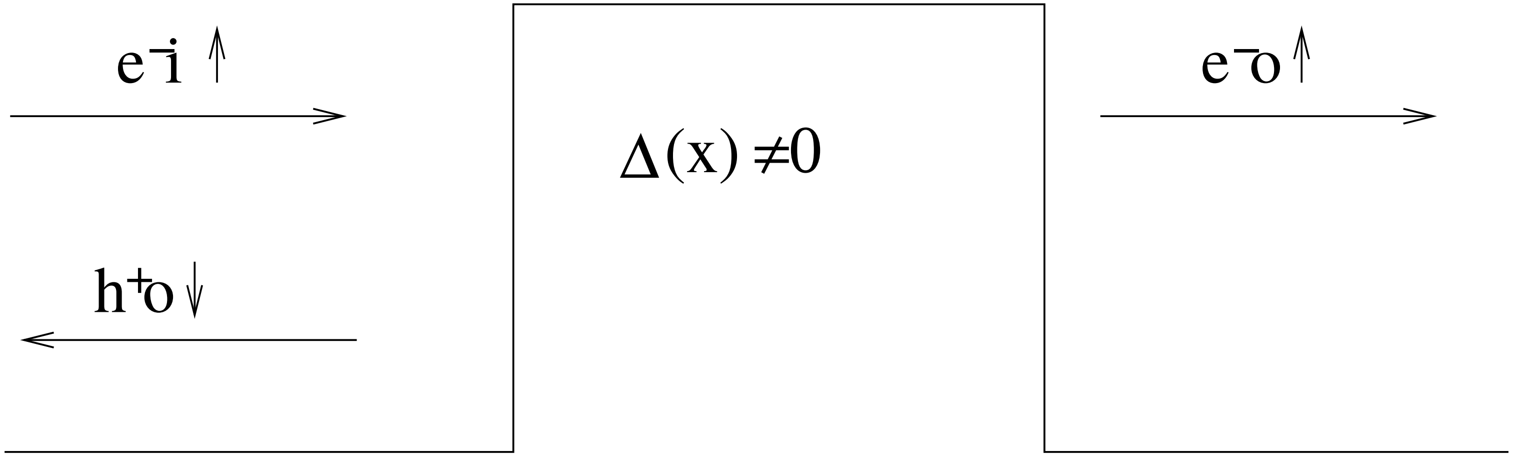
Proximity effect

$$H_s = \int dx (\Delta(x) \psi_+^\dagger \psi_-^\dagger + \Delta^*(x) \psi_- \psi_+)$$

$\Delta(x) \neq 0$ when $0 < x < \ell$.

Scattering channels: Andreev reflection and normal transmission.



$$\psi_{i/o,\sigma}(t) = \int \frac{d\epsilon}{2\pi\hbar} e^{-i\epsilon t/\hbar} \psi_{i/o,\sigma}(\epsilon)$$

$$\psi_{\uparrow,o}(\epsilon) = t(\epsilon)\psi_{\uparrow,i}(\epsilon) - \frac{r^*(\epsilon)t(\epsilon)}{t^*(\epsilon)}\psi^\dagger_{\downarrow,i}(-\epsilon),$$

$$\psi^\dagger_{\downarrow,o}(-\epsilon) = r(\epsilon)\psi_{\uparrow,i}(\epsilon) + t(\epsilon)\psi^\dagger_{\downarrow,i}(-\epsilon).$$

Average Current in the superconductor

$$I_S = -ev_F \sum_\sigma (\psi^\dagger_{o,\sigma}\psi_{o,\sigma} - \psi^\dagger_{i,\sigma}\psi_{i,\sigma})(t)$$

$$\langle I_S \rangle = \frac{e}{\pi\hbar}\int_{-\infty}^{\infty} |r(\epsilon)|^2 (n_F(\epsilon - eV_L) + n_\downarrow(-\epsilon - eV_R) - 1)\, d\epsilon\,,$$

For $|eV_L|, |eV_R| \ll |\Delta|$, $I_S = \frac{2e^2}{h}|r(0)|^2(V_R + V_L)$. For $\ell \gg \hbar v_F/|\Delta|$, $|r(0)| \to 1$.

Current noise

$$S(\omega) = \frac{1}{2}\int dt e^{-i\omega t}\langle\{I_S(t), I_S(0)\}\rangle$$

$$S(\omega=0) = \frac{4e^2}{h}\int_{-\infty}^{\infty}|r(\epsilon)|^2\left(n_\uparrow(1-n_\uparrow)+n_\downarrow(1-n_\downarrow)\right)(\epsilon)\,d\epsilon$$

$$+\frac{8e^2}{h}\int_{-\infty}^{\infty}|r(\epsilon)\,t(\epsilon)|^2\left((n_\uparrow+n_\downarrow-1)(\epsilon)\right)^2 d\epsilon\,.$$

$\Rightarrow$ Thermal noise plus partition noise. The partition noise vanishes for a long superconducting contact.

Perspectives

1. Interactions in the leads: Kane-Fisher problem if short contact (Sato et al. ArXiv:1003.4316).
2. Josephson junctions QSH edge / superconductor / QSH edge
3. Ahronov-Bohm interferometry