Universal scaling at band-tuned metal-insulator transitions

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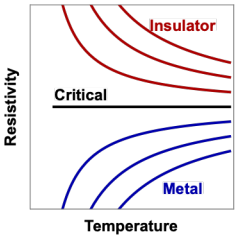
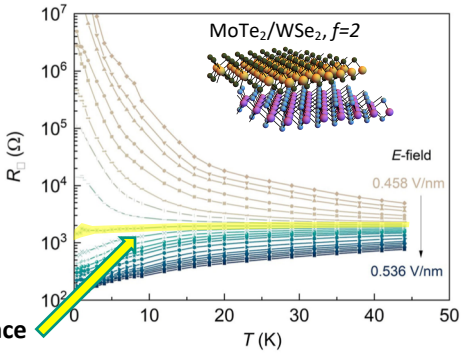


1. Traditional picture of **metal-insulator transition**:

Metal has $\sigma(T=0) \neq 0$ and $d\rho/dT > 0$

Insulator has $\sigma(T=0) = 0$ and $d\rho/dT < 0$

Critical has $\rho(T)$ constant



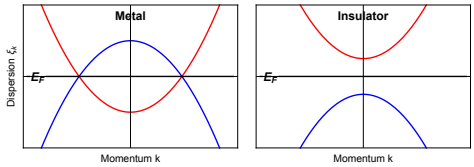
2. Moiré heterostructures can be **tuned** to a metal-insulator **transition**

Example: **$MoTe_2/WSe_2$** at full filling of the flat valence band

Appears to confirm the traditional picture with **constant critical resistance**

Ref: Li et al, Nature 2021

3. Theory of **band-tuned** transition

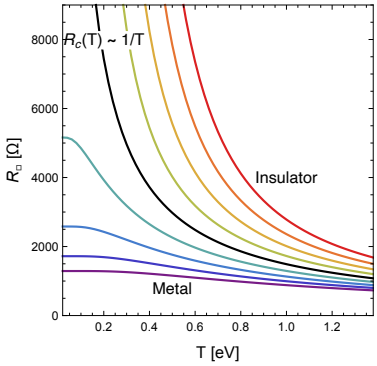


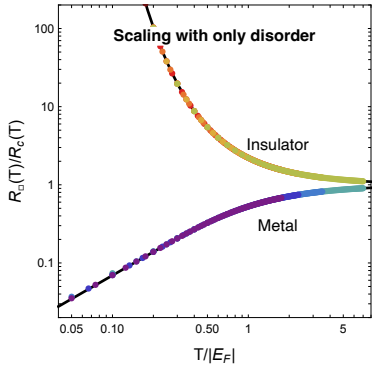
Metal = overlapping bands, **insulator** = gap between bands

Use **Kubo** formula with **weak disorder**

$$\sigma = \frac{\pi}{2} \sum_{\alpha=x,y} \int \frac{d^2p}{(2\pi)^2} \int dz\, A(\mathbf{p},z) j_\alpha(\mathbf{p}) A(\mathbf{p},z) j_\alpha(\mathbf{p}) \left(-\frac{\partial n_F(z)}{\partial z}\right)$$

Spectral function Current operator $\mathbf{j}(\mathbf{p}) = \frac{e\mathbf{p}}{m}$





Exact result:

$$\sigma(E_F, T) = \frac{e^2}{h} \tau T \log\left[1 + e^{E_F/T}\right]$$

Disorder scattering rate

Band overlap

Different from traditional picture:

Metal can have $d\rho/dT < 0$ (**"fake insulator"**)

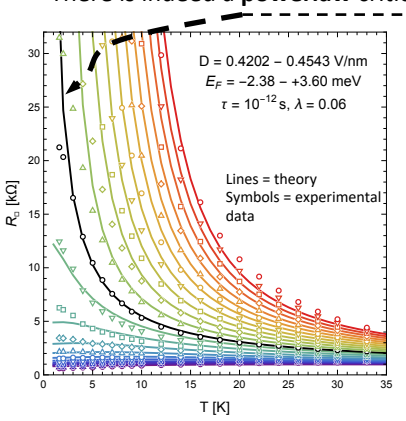
Critical state has **powerlaw** resistance

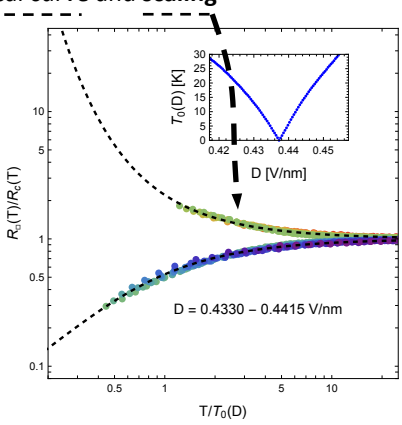
$$R_c \sim 1/T$$

Close to the transition, resistance curves satisfy **scaling** $\sigma(E_F, T) = \sigma_c(T) f(E_F/T)$

4. Application to **experimental results** in $MoTe_2/WSe_2$

There is indeed a **powerlaw** critical curve and **scaling**





5. Summary

Don't believe something is an "insulator" just because $d\rho/dT < 0$

Do a scaling analysis to check for proper critical behavior