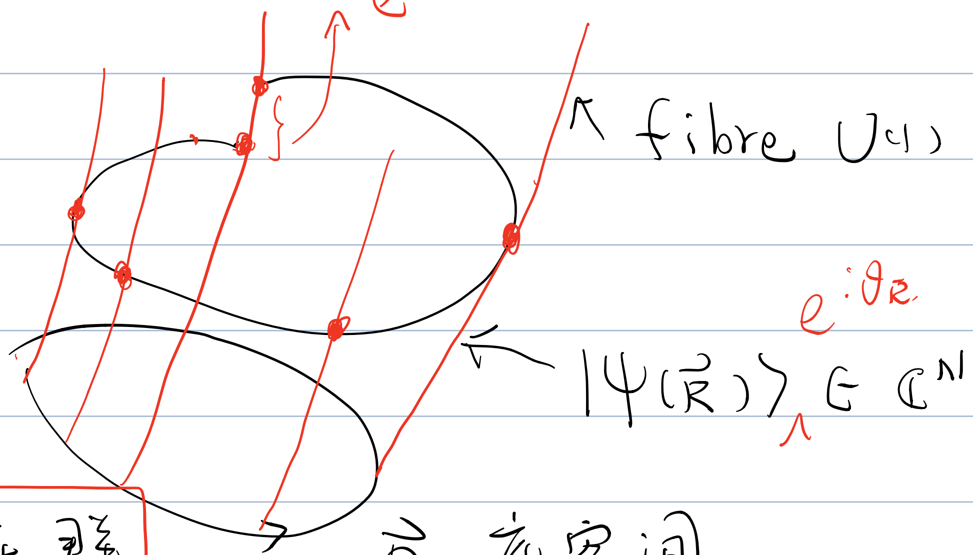
4.15.



几何相 → Zak phase (1989) / 1d 固体 / Bloch } wannier

$\gamma = i\oint \langle \psi_k | \partial_k | \psi_k \rangle dk$ ~ 极化

Topo insulator {
- Haldane model (1988)
- Qi-Wu-Zhang (QWZ model 2005)

$\frac{1}{4\pi}$ ~ 立体角.

Hall effect 1981 克里青 (Klitzing).

$\sigma = ne^2/h$ ⇒ 测精细结构常数 (FSS)

(2页) Laughlin argument (PRB).

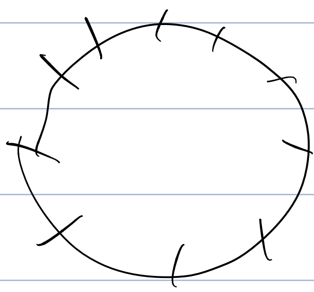
Hw. 量子化热导的推导.

Ref:

1. Laughlin. Nobel. lecture. 1998 ⇒ Nobel prize.
2. Laughlin. PRB. 23. 5632. (1981). 直观图象.
3. Haldance.

↳ 整数Hall电导,不是朗道能级更本质. 指出规范势更加本质.

计算/数值方法



$e^{i\theta_{i+1}}$ $e^{i\theta_i}$

$$\gamma = i\int\langle\psi_k|\nabla_k|\psi_k\rangle dk$$

$$= i\sum_i \frac{\langle\psi|\big(|\psi_{i+1}\rangle - |\psi_i\rangle\big)}{\delta k}\cdot\delta k$$

$$= i\sum_i\big(\langle\psi_i|\psi_{i+1}\rangle - 1\big) \mod(2\pi)$$

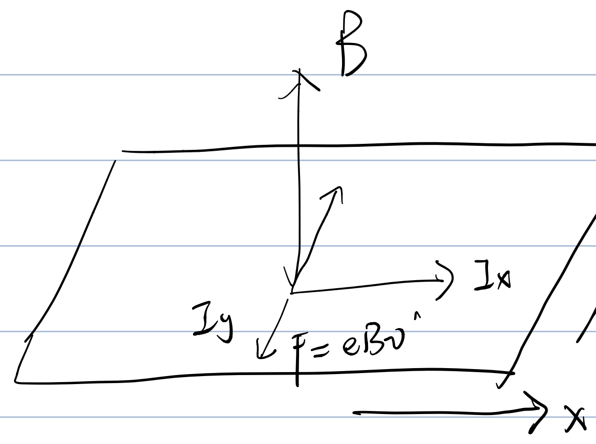
$e^{i(\theta_{i+1}-\theta_i)}$

⇒ 导致结果不稳定(不对)

若取ψ_i为某一种规范形式,(smooth)

对的方法:

$$\Rightarrow \prod_i\big(\langle\psi_i|\psi_{i+1}\rangle\big)$$



✓ $eE = evB$

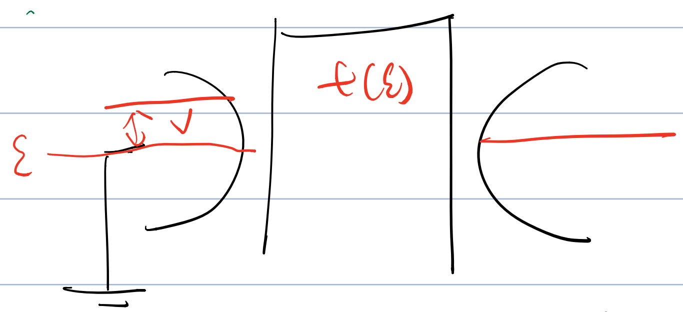
✓ $J = nevd$

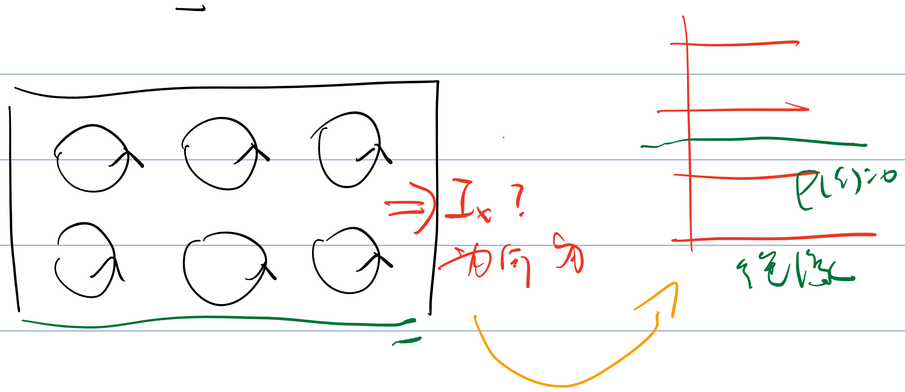
$$G = \frac{I}{U} = \frac{nevd}{Ed} = \frac{nev}{E} = \boxed{\frac{ne}{B}}$$

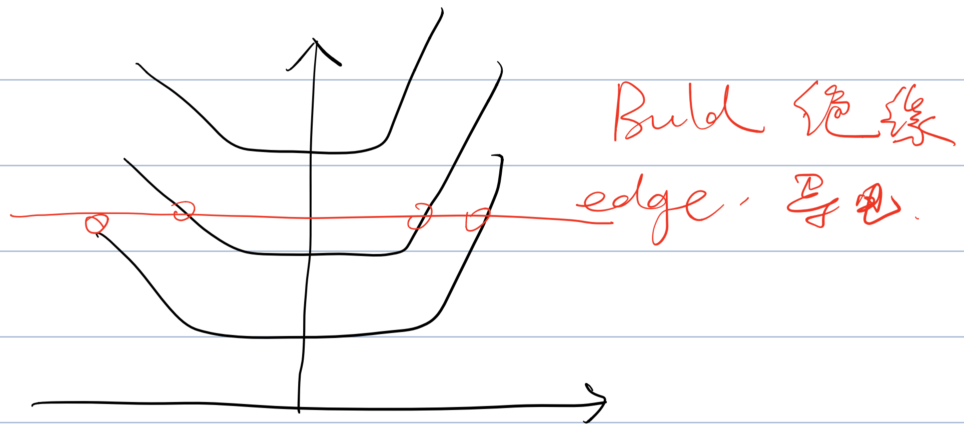
DOS $\rho(\varepsilon) \neq 0$

Landau 能级与电导 ⇒ 导电 ⇒ $G = 0$ for insulator

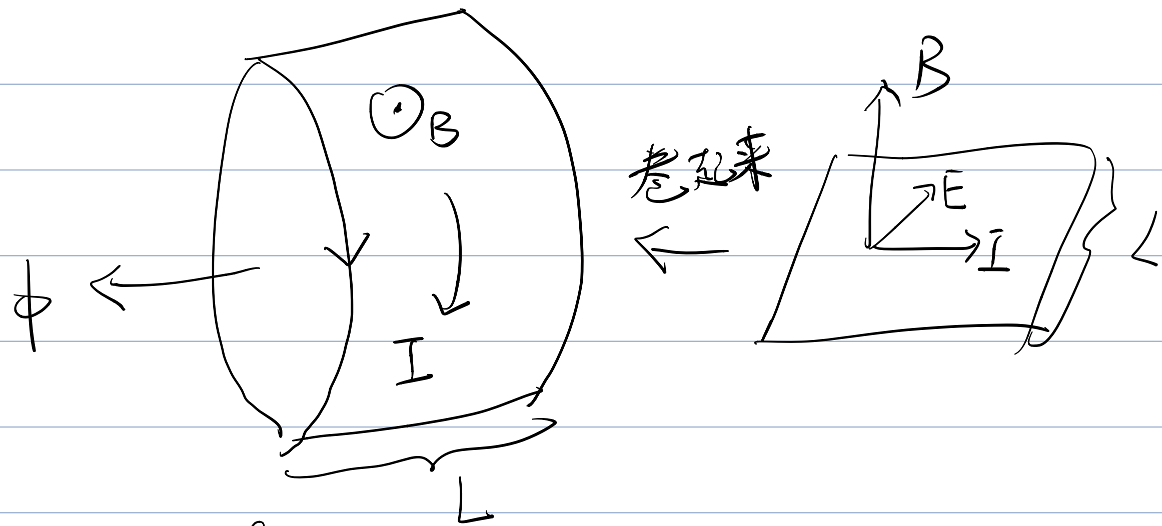
$$\int \rho_L(\varepsilon + V)\,(1 - \rho_R(\varepsilon))\, t(\varepsilon)\, d(\varepsilon).$$







Laughlin 解释：应用于热导.



$$\phi = \oint \vec{A} \cdot d\vec{l}$$

$$I = c\left(\frac{\partial U}{\partial \phi}\right) = c\,\frac{\delta U}{(\delta \phi)}$$

Feynman - Hellman 定理

$$\langle \psi(\phi) | \left(\frac{\partial H}{\partial \phi}\right) | \psi(\phi) \rangle = \frac{\partial}{\partial \phi} \underbrace{\langle \psi(\phi) | H(\phi) | \psi(\phi) \rangle}_{U(\phi)}$$

$$= \partial U / \partial \phi.$$

$$\partial H/\partial \phi = \frac{1}{c}(\partial H/\partial A)$$

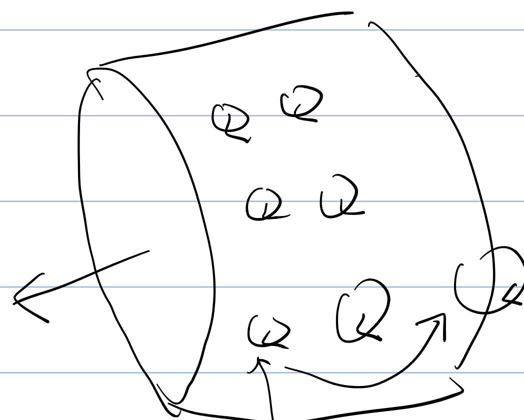
$$\uparrow \quad H = (p - eA)^2/2m + U(r)$$

$$= \frac{1}{c}\, e/2m\, \pi \sim \frac{e}{c} v \sim j$$

$$\uparrow$$

$$\pi = mv$$

$$I = c\,\partial U/\partial \phi = c(\delta U/\delta \phi).$$



ϕ

$\downarrow$

$\phi + n\pi$ 会把 ⊖ 从一边挪动到另一边

$\Downarrow$

所以 $\delta U = neV$. $\delta \phi = (hc/e)$.

$$\therefore neV/hc/e = ne^2V/h.$$

$$G = I/V = ne^2V/h.$$