

Title: Spontaneous Broken Symmetry 6B

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URL: <http://pirsa.org/07120011>

Abstract:

$$[H_{red}, d_k] = -[c_k, c_k^\dagger]$$

$$H_{red} = \sum_k \epsilon_k n_{k\sigma} + \sum_{k, k'} V_{kk'} [b_k^\dagger c_{k'} + h.c.]$$

Sp analogy to understand the gap

$$b_k, b_k^\dagger, \frac{1 - n_k - n_{-k}}{2}$$

$$b_k + b_k^\dagger = \tau_x \quad \tau_z$$

$$i(-) = \tau_y$$

$\frac{1}{2} \sum_{k=1}^n \frac{1}{k^2}$

$\frac{1}{2} \sum_{k=1}^n \frac{1}{k^2}$

$\frac{1}{2} \sum_{k=1}^n \frac{1}{k^2}$

$\frac{1}{2} \sum_{k=1}^n \frac{1}{k^2} = O(n)$

$\frac{1}{2} \sum_{k=1}^n \frac{1}{k^2} = \frac{1}{2} \sum_{k=1}^n \frac{1}{k^2}$

$\frac{1}{2} \sum_{k=1}^n \frac{1}{k^2}$

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$\frac{1}{2} \sum_{k=1}^n \frac{1}{k^2}$

$$\psi(r) = \frac{1}{r_0}$$

$$i\dot{\Psi}(r) = H_0 \Psi(r)$$

□

$$\hat{\Psi}(r) = H_0 \Psi(r) + \Delta(r) \Psi^\dagger(r \downarrow)$$

# Landau Ginzburg Action

(In addition to spin order, where  $|\vec{\Delta}|^2$  comes from)

Gauge Invariance  $\vec{\nabla} \rightarrow \vec{\nabla} - 2e\vec{A}$

Quantized Flux, Josephson

$$H_{\text{em}} = \sum_k \xi_k \pi_k + \sum_{\lambda, k} V_{\lambda, k} a_{\lambda, k}^\dagger a_{\lambda, k}^\dagger a_{\lambda, k} a_{\lambda, k}$$

$\langle BCS || H_{\text{em}} || BCS \rangle = 2$  types of terms in product SC.

$$H_{\text{red}} = \sum_k \xi_k \langle \pi_k \rangle + \sum_{\lambda, k} V_{\lambda, k} \langle b_{\lambda, k}^\dagger \rangle \langle b_{\lambda, k} \rangle$$

$$m_k = v_k^2$$

$$\langle b_{\lambda, k} \rangle = u_k v_k$$

+ h.c.

Define  $u_k v_k = \sin 2\theta_k$

$$m_k = \cos^2 \theta_k$$

split,

$$\xi_k \tan 2\theta_k = \frac{1}{2} \sum_{\lambda, k} V_{\lambda, k} \sin 2\theta_k$$

$$\text{Define } \Delta_k = - \sum_{\lambda} V(\lambda, k) \frac{\sin 2\theta_{\lambda}}{2}$$

$$\tan 2\theta_k = - \frac{\Delta_k}{\xi_k}$$

$$\sin 2\theta_k = \frac{\Delta_k}{E_k} \quad \cos 2\theta_k = - \frac{\xi_k}{E_k}$$

$$E_k = \sqrt{\xi_k^2 + \Delta_k^2}$$

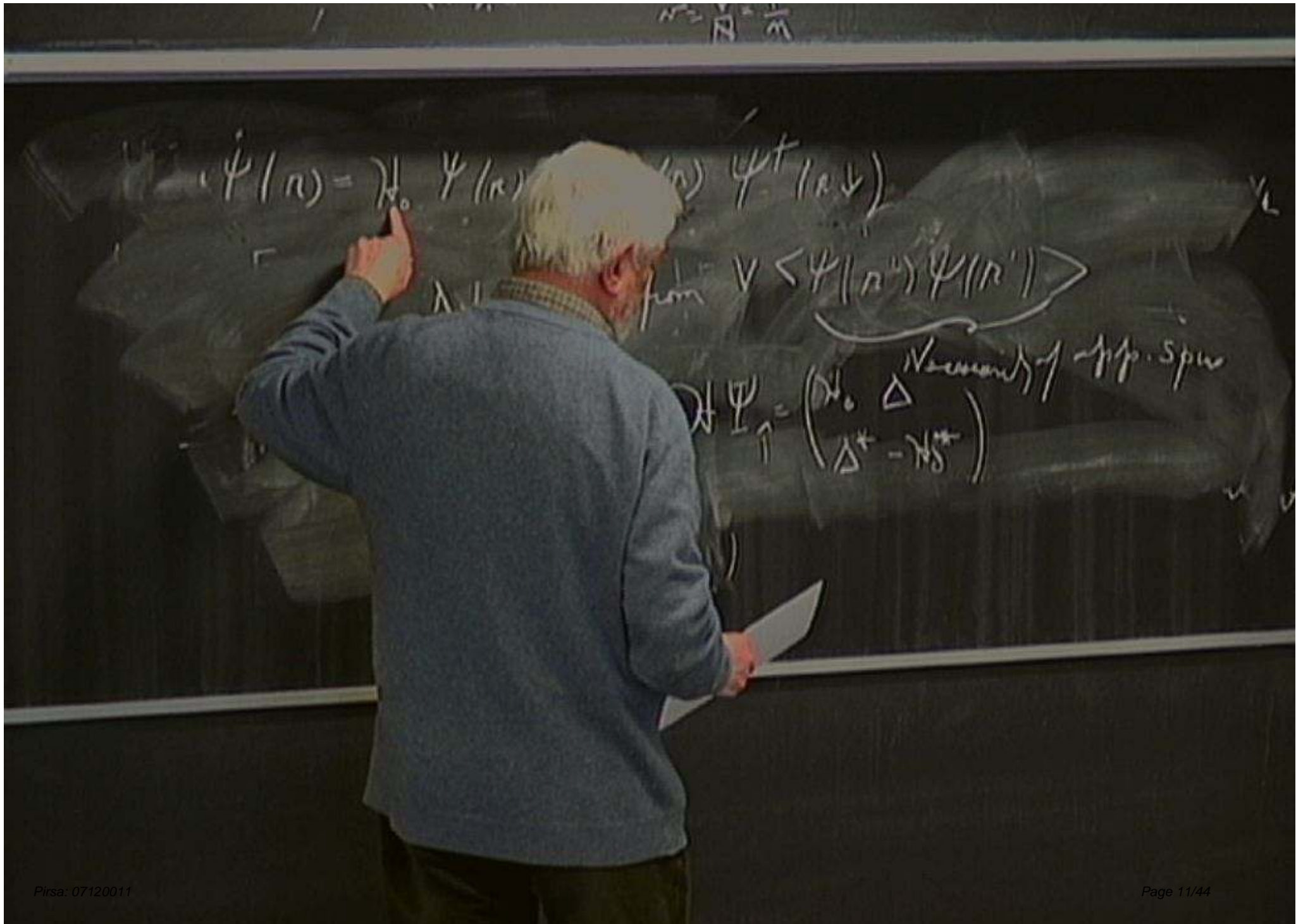
$$\psi(r) = H_0 \psi(r) + \Delta(r) \psi^*(r, \psi)$$

$\psi(r) = \psi(r) + \Delta(r) \psi^*(r)$   
 term comes from  $\langle \psi(r) | \psi(r) \rangle$   
 necessary for spin

$$\hat{\Psi}(r) = H_0 \Psi(r) + \Delta(r) \Psi^+(r, \psi)$$

$\Delta$  term comes from  $\int \langle \Psi(r'') \Psi(r'') \rangle$

vacuum expectation value



$$\hat{N} = \hat{N}^\dagger = \hat{N}$$

$$\hat{H} \Psi(r) = E_0 \Psi(r) \quad \hat{H} = \hat{H}_0 + \hat{V} \quad \Psi^\dagger(r) = \langle \Psi(r) |$$

$$\langle \Psi(r') | \Psi(r) \rangle$$

$$\hat{H} \Psi \uparrow = \begin{pmatrix} E_0 & \Delta \\ \Delta^\dagger & E_0^* \end{pmatrix}$$

Vacuum state of spin-up particles

$$\hat{H}\Psi(r) = H_0 \Psi(r) + \Delta(r) \Psi^\dagger(r, \psi)$$

comes from  $\int \langle \Psi(r) | \Psi(r') \rangle$

$$\hat{H}\Psi(r) =$$

$$H\Psi = \begin{pmatrix} H_0 & \Delta \\ \Delta^\dagger & -H_0^* \end{pmatrix}$$

*vacuum state of spin*

$$+ \Delta(r) \Psi(r)$$

$$\dot{\Psi}(n) = H_0 \Psi(n) + \Delta(n) \Psi^\dagger(n)$$

$\Delta$  term comes from  $V \langle \Psi(n) \Psi(n') \rangle$

$$\vec{\Psi}(n) = \begin{pmatrix} \Psi(n \uparrow) \\ \Psi^\dagger(n \downarrow) \end{pmatrix} \Rightarrow H \vec{\Psi} = \begin{pmatrix} H_0 & \Delta \\ \Delta^* & -H_0^* \end{pmatrix} \vec{\Psi}$$

*vacuum / spin*

$$E_n u(n) = H_0 u(n) + \Delta(n) v(n)$$

$$E_n v(n) = -H_0^* v(n) + \Delta^*(n) u(n)$$

$$\psi(r) = H_0 \psi(r) + \Delta(r) \psi^*(r)$$

comes from  $V \langle \psi(r) \psi(r) \rangle$

$$H \Psi = \begin{pmatrix} H_0 & \Delta \\ \Delta^* & -H_0^* \end{pmatrix} \Psi$$

Necessity of -pp. Spw

$$\begin{aligned} H u(r) + \Delta(r) v(r) & \text{ where } \Delta(r) = V \langle \psi(r) \psi(r) \rangle \\ H^* v(r) + \Delta^*(r) u(r) & \end{aligned}$$

To describe flow



$t_1$   $t_2$

To describe flow

$$\Delta(r) = |\Delta| e^{2i\eta \cdot r}$$

To describe flow

$$\Delta(r) = |\Delta| e^{2i\eta \cdot r}$$

$$E_{\mathbf{k}} u_{\mathbf{k}} = \sum_{\mathbf{k}+\mathbf{q}} u_{\mathbf{k}+\mathbf{q}} + |\Delta| e^{2i\eta \cdot r} v_{\mathbf{k}}$$

$$E_{\mathbf{k}} v_{\mathbf{k}} = -\sum_{\mathbf{k}-\mathbf{q}} v_{\mathbf{k}-\mathbf{q}} + |\Delta| e^{-2i\eta \cdot r} u_{\mathbf{k}}$$

16 - 1  $\bar{c}_4$

$$\frac{\langle \Delta N^2 \rangle}{\langle N \rangle} = \frac{1}{\beta} \frac{1}{\langle N \rangle} \frac{\partial \langle N \rangle}{\partial \mu} = \frac{1}{\beta N} \frac{\partial \ln Z}{\partial \mu}; \quad d\mu = \mu - d p \text{ at fixed } T$$

$$\frac{\partial \langle N \rangle}{\partial \mu} = \frac{\partial \langle N \rangle}{\partial \mu}$$

$$\Psi(r) = H_0 \Psi(r) + \Delta(r) \Psi^\dagger(r)$$

mes. from  $\int \langle \Psi(r) \Psi^\dagger(r') \rangle$

$$H \Psi = \begin{pmatrix} H_0 & \Delta \\ \Delta^\dagger & -H_0^\dagger \end{pmatrix} \Psi$$

(vacuum) - pp. spin

$$= -H_0^\dagger \Psi(r) + \Delta^\dagger \Psi(r) \quad \text{where } \Delta(r) = \int \langle \Psi(r') \Psi^\dagger(r'') \rangle$$

$$\frac{\langle \Delta N^2 \rangle}{\langle N \rangle} = \frac{1}{\beta} \frac{1}{\langle N \rangle} \frac{\partial \langle N \rangle}{\partial \mu} = \frac{1}{\beta \langle N \rangle} \frac{\partial \ln Z}{\partial \mu}; \quad d\mu = \mu - d\mu \text{ at fixed } T$$

$$\mu = \frac{\langle N \rangle}{\beta} = \frac{1}{\beta}$$

$$\Psi(r) = H_0 \Psi(r) + \Delta(r) \Psi^\dagger(r, \downarrow)$$

mes. from  $\forall \langle \Psi(r'') \Psi(r') \rangle$

$$\Psi(r)$$

$$H \Psi = \begin{pmatrix} H_0 & \Delta \\ \Delta^\dagger & -H_0^\dagger \end{pmatrix} \Psi$$

vacuum state - spin

$$\begin{aligned} H u(r) + \Delta(r) v(r) \\ H^\dagger v(r) + \Delta^\dagger u(r) \end{aligned} \quad \text{where } \Delta(r) = V \langle \Psi(r') \Psi(r'') \rangle$$

$$\frac{\langle \Delta N^2 \rangle}{\langle N \rangle} = \frac{1}{\beta} \frac{1}{\langle N \rangle} \frac{\partial \langle N \rangle}{\partial \mu} = \frac{1}{\beta N} \frac{\partial \ln Z}{\partial \mu}; \quad d\mu = \mu - d p \text{ at fixed } T$$

$$\Psi(r) = H_0 \Psi(r) + \Delta(r) \Psi^+(r \downarrow)$$

$$\Delta(r) \text{ comes from } V \langle \Psi(r'') \Psi(r') \rangle$$

$$\bar{H} \Psi = \begin{pmatrix} \Psi(r \uparrow) \\ \Psi^+(r \downarrow) \end{pmatrix}, \quad H \Psi = \begin{pmatrix} H_0 & \Delta \\ \Delta^+ & -H_0^+ \end{pmatrix} \text{ spin}$$

$$E_u u(r) = H_0 u(r) + \Delta(r) v(r) \quad \text{where } \Delta(r) = V \langle \Psi(r \uparrow) \Psi(r \downarrow) \rangle$$

$$E_v v(r) = -H_0^+ v(r) + \Delta^+(r) u(r)$$

To describe flow

$$\Delta(\eta) = |\Delta| e^{2i\eta \cdot \eta}$$

$$E_{\lambda} u_{\lambda} = z_{\lambda} u_{\lambda} + |\Delta| e^{2i\eta \cdot \eta} v_{\lambda}$$

$$E_{\lambda} v_{\lambda} = -z_{\lambda} v_{\lambda} + |\Delta| e^{-2i\eta \cdot \eta} u_{\lambda}$$

$$u_{\lambda} = u_{\lambda}^{(0)} e^{i\eta \cdot \eta}$$

$$v_{\lambda} = v_{\lambda}^{(0)} e^{-i\eta \cdot \eta}$$

To describe flow

$$\Delta(r) = |\Delta| e^{2i\eta \cdot r}$$

$$E_k u_k = \frac{\hbar^2 k^2}{2m} u_k + |\Delta| e^{2i\eta \cdot r} v_k$$

$$E_k v_k = -\frac{\hbar^2 k^2}{2m} v_k + |\Delta| e^{-2i\eta \cdot r} u_k$$

$$u_k = u_k^{(0)} e^{i\eta \cdot r}$$

$$v_k = v_k^{(0)} e^{-i\eta \cdot r}$$

$\langle b_k \rangle_{RS}$  underflow  $\rightarrow \langle a_{k+\eta} a_{-k+\eta} \rangle$

✓ To describe flow



$$\Delta(\mathbf{r}) = |\Delta| e^{2i\mathbf{q} \cdot \mathbf{r}}$$

$$E_k u_k = \sum_{l \neq k} u_{kl} + |\Delta| e^{2i\mathbf{q} \cdot \mathbf{r}} v_k$$

$$E_k v_k = -\sum_{l \neq k} v_{kl} + |\Delta| e^{-2i\mathbf{q} \cdot \mathbf{r}} u_k$$

$$u_k = u_k^{(0)} e^{i\mathbf{q} \cdot \mathbf{r}}$$

$$v_k = v_k^{(0)} e^{-i\mathbf{q} \cdot \mathbf{r}}$$

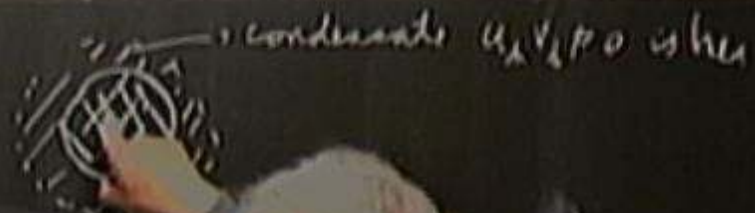
$\langle b_k \rangle_{\text{res}}$  underflow  $\rightarrow \langle a_{k+\mathbf{q}} \rangle_{\text{res}}$

To describe flow

$$\Delta(\psi) = |\Delta| e^{2i\theta \cdot R}$$

$$E_k u_k = \sum_{k'} u_{k'} + |\Delta| e^{2i\theta \cdot R} v_k$$

$$E_k v_k = -\sum_{k'} v_{k'} + |\Delta| e^{-2i\theta \cdot R} u_k$$

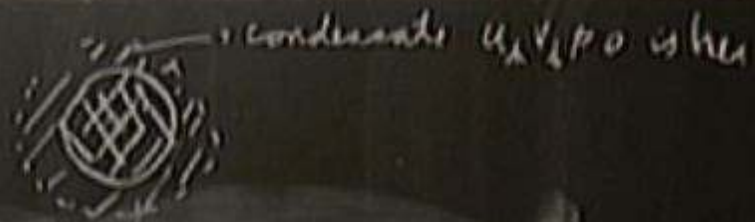


$$u_k e^{i\theta \cdot R}$$

$$v_k e^{-i\theta \cdot R}$$

flow  $\rightarrow \langle \rho_{k+\pi} \rho_{-k+\pi} \rangle$

To describe flow



$$\Delta(r) = |\Delta| e^{2i\theta \cdot r}$$

$$E_k u_k = \epsilon_{k+q} u_k + |\Delta| e^{2i\theta \cdot r} v_k$$

$$E_k v_k = -\epsilon_{k-q} v_k + |\Delta| e^{-2i\theta \cdot r} u_k$$

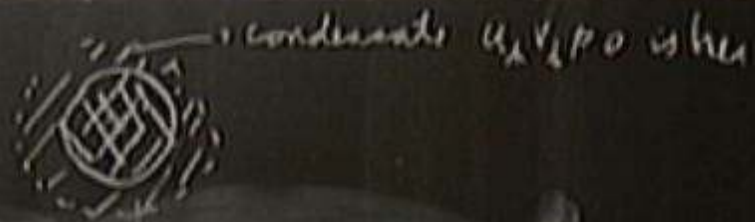
$$u_k = u_k^{(0)} e^{i\theta \cdot r}$$

$$v_k = v_k^{(0)} e^{-i\theta \cdot r}$$

$\langle b_k \rangle_{res}$  underflow  $\rightarrow \langle a_{k+q} a_{-k+q} \rangle$

To describe flow

$$\Delta(\mathbf{r}) = |\Delta| e^{2i\mathbf{q} \cdot \mathbf{r}}$$



$$\sum_{\mathbf{k} \rightarrow \mathbf{k}'} u_{\mathbf{k}} + |\Delta| e^{2i\mathbf{q} \cdot \mathbf{r}} v_{\mathbf{k}}$$

$$-\sum_{\mathbf{k} \leftarrow \mathbf{k}'} v_{\mathbf{k}} + |\Delta| e^{-2i\mathbf{q} \cdot \mathbf{r}} u_{\mathbf{k}}$$

$$u_{\mathbf{k}} = u_{\mathbf{k}}^{(0)} e^{i\mathbf{q} \cdot \mathbf{r}}$$

$$v_{\mathbf{k}} = v_{\mathbf{k}}^{(0)} e^{-i\mathbf{q} \cdot \mathbf{r}}$$

$\langle b_{\mathbf{k}} \rangle_{NS}$  underflow  $\rightarrow \langle a_{\mathbf{k}+\mathbf{q}} a_{-\mathbf{k}+\mathbf{q}} \rangle$

To describe flow

condensate  $u_k, v_k \neq 0$  when



$$\Delta(r) = |\Delta| e^{2i\theta \cdot r}$$

$$E_k u_k = \epsilon_{k+q} u_k + |\Delta| e^{2i\theta \cdot r} v_k$$

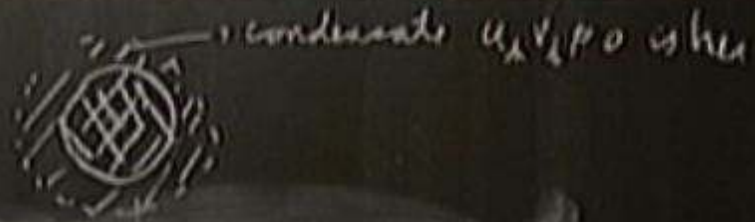
$$E_k v_k = -\epsilon_{k-q} v_k + |\Delta| e^{-2i\theta \cdot r} u_k$$

$$u_k = u_k^{(0)} e^{i\theta \cdot r}$$

$$v_k = v_k^{(0)} e^{-i\theta \cdot r}$$

$\langle b_k \rangle_{res}$  underflow  $\rightarrow \langle a_{k+q} a_{-k+q} \rangle$

To describe flow



$$\Delta(r) = |\Delta| e^{2i\theta \cdot r}$$

$$E_k u_k = \sum_{k'} \epsilon_{k+k'} u_{k'} + |\Delta| e^{2i\theta \cdot k} v_k$$

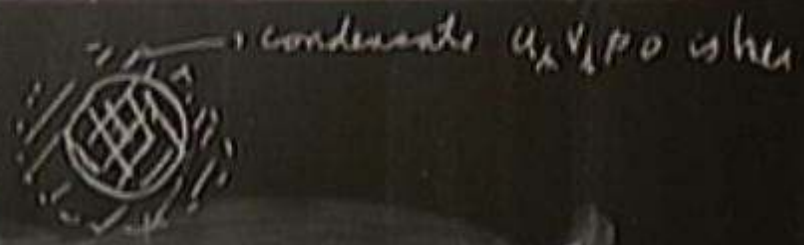
$$E_k v_k = -\sum_{k'} \epsilon_{k-k'} v_{k'} + |\Delta| e^{-2i\theta \cdot k} u_k$$

$$E_k = \frac{\sum_{k'} \epsilon_{k+k'} - \sum_{k'} \epsilon_{k-k'}}{2} + \sqrt{\left( \frac{\sum_{k'} \epsilon_{k+k'} + \sum_{k'} \epsilon_{k-k'}}{2} \right)^2 + \Delta^2 / 2}$$

$$E_k = E_k^0 - \frac{\hbar \cdot \gamma}{m}$$

11  $\bar{E}_k$

To describe flow



$$\Delta(r) = |\Delta| e^{i\theta}$$

$$E_k u_k = \epsilon_k u_k$$

$$E_k v_k = \epsilon_k v_k$$

$$E_k$$

$$|\Delta| e^{2i\theta} v_k$$

$$-2i\theta v_k$$

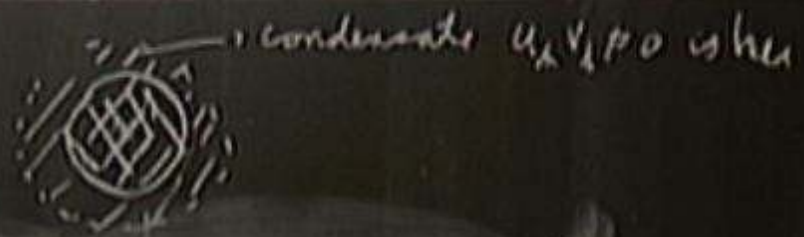
$$+ \frac{\hbar^2 v_F^2 k^2}{2} + \frac{\Delta^2}{2}$$

$$E_k = E_k^0 - \frac{\hbar \cdot \gamma}{m}$$

LH eq for  $\Delta(r)$

$$\frac{\hbar^2 v_F^2 k^2}{2} + \frac{\Delta^2}{2}$$

To describe flow



$$\Delta(r) = |\Delta| e^{2i\eta \cdot r}$$

$$E_k u_k = \xi_{k+\eta} u_k + |\Delta| e^{2i\eta \cdot r} v_k$$

$$E_k v_k = -\xi_{k-\eta} v_k + |\Delta| e^{-2i\eta \cdot r} u_k$$

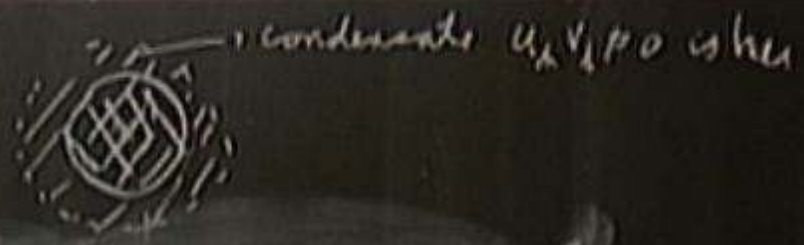
$$E_k = \frac{\xi_{k+\eta} - \xi_{k-\eta}}{2} + \left[ \frac{(\xi_{k+\eta} + \xi_{k-\eta})^2 + \Delta^2}{2} \right]^{1/2}$$

$$E_k = E_k^0 - \frac{\lambda \cdot \eta}{m}$$

LH eq for  $\Delta(r)$ , Near  $T_c$

$$S = -M^2 |\Delta|^2 + \lambda |\Delta|^4$$

To describe flow



$$\Delta(r) = |\Delta| e^{2i\theta \cdot r}$$

$$E_k u_k = \xi_{k+1} u_k + |\Delta| e^{2i\theta \cdot r} v_k$$

$$E_k v_k = -\xi_{k-1} v_k + |\Delta| e^{-2i\theta \cdot r} u_k$$

$$E_k = \frac{\xi_{k+1} - \xi_{k-1}}{2} + \left[ \frac{(\xi_{k+1} + \xi_{k-1})^2 + \Delta^2}{2} \right]^{1/2}$$

$$E_k = E_k^0 - \frac{\lambda \cdot \eta}{m}$$

LH eq for  $\Delta(r)$ , Near  $T_c$

$$S = -M^2 |\Delta|^2 + \lambda |\Delta^2|^2 + |\nabla \Delta|^2$$

To describe flow

$$\Delta(r) = |\Delta| e^{2i\theta \cdot r}$$

$$E_h u_h = \xi_{h+1} u_h + |\Delta| e^{2i\theta \cdot r}$$

$$E_h v_h = -\xi_{h-1} v_h + v_h$$

$$E_h = \frac{\xi_{h+1} - \xi_{h-1}}{2} +$$

condensate  $u_h v_h \neq 0$  is here

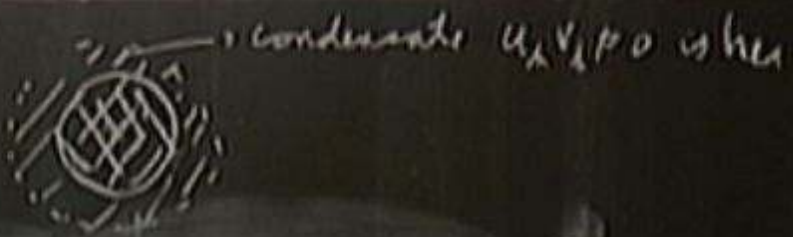


$$E_h = E_h^0 - \frac{\lambda \cdot \Gamma}{m}$$

LG eq for  $\Delta(r)$ , Near  $T_c$

$$S = m^4 |\Delta|^4 + \lambda |\Delta^2|^2 + |\nabla \Delta|^2$$

To describe flow



$$\Delta(r) = |\Delta| e^{2i\eta \cdot r}$$

$$E_k u_k = \xi_{k+\eta} u_k + |\Delta| e^{2i\eta \cdot r} v_k$$

$$E_k v_k = -\xi_{k-\eta} v_k + |\Delta| e^{-2i\eta \cdot r} u_k$$

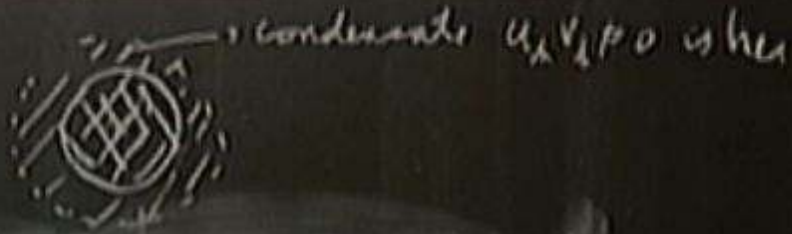
$$E_k = \frac{\xi_{k+\eta} - \xi_{k-\eta}}{2} + \left[ \frac{(\xi_{k+\eta} + \xi_{k-\eta})^2 + \Delta^2}{2} \right]^{1/2}$$

$$E_k = E_k^0 - \frac{\lambda \cdot \eta}{m}$$

LH eq for  $\Delta(r)$ , Near  $T_c$

$$S_{\Delta} = -M^2 |\Delta|^2 + \lambda |\Delta^2|^2 + |\nabla \Delta|^2$$

To describe flow



$$\Delta(r) = |\Delta| e^{2i\theta \cdot r}$$

$$E_k u_k = \xi_{k+q} u_k + |\Delta| e^{2i\theta \cdot r} v_k$$

$$E_k v_k = -\xi_{k-q} v_k + |\Delta| e^{-2i\theta \cdot r} u_k$$

$$\bar{E}_k = \frac{\xi_{k+q} - \xi_{k-q}}{2} + \left[ \frac{(\xi_{k+q} + \xi_{k-q})^2}{2} + \Delta^2 \right]^{1/2} \bar{A} = 0$$

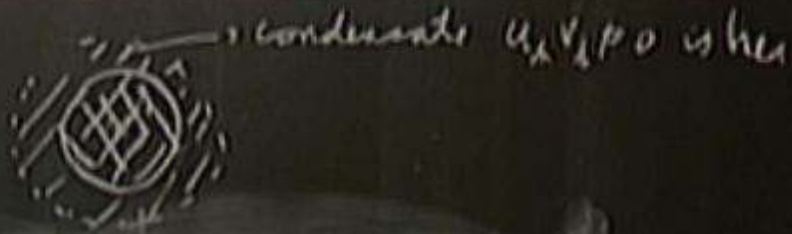
$$E_k = \vec{E}_k^0 - \frac{\lambda \cdot \vec{r}}{m}$$

LH eq for  $\Delta(r)$ , Near  $T_c$

$$S_{\Delta} = -\mu^2 |\Delta|^2 + \lambda |\Delta^2|^2 + |\nabla \Delta|^2$$

$$\bar{A} = 0 \quad \sqrt{((\nabla - 2i\theta \cdot \vec{r}) \Delta)^2}$$

To describe flow



$$\Delta(\mathbf{r}) = |\Delta| e^{2i\theta \cdot \mathbf{r}}$$

$$E_k u_k = \xi_{k+\eta} u_k + |\Delta| e^{2i\theta \cdot \mathbf{r}} v_k$$

$$E_k v_k = -\xi_{k-\eta} v_k + |\Delta| e^{-2i\theta \cdot \mathbf{r}} u_k$$

$$E_k = \xi_{k+\eta} - \xi_{k-\eta} + \left[ \frac{(\xi_{k+\eta} + \xi_{k-\eta})^2}{2} + \frac{\Delta^2}{r^2} \right] \quad \bar{A} = 0 \quad \sqrt{((\nabla - 2\eta\bar{A})\Delta)^2}$$

$$E_k = E_k^0 - \frac{\mathbf{k} \cdot \mathbf{J}}{m}$$

LG eq for  $\Delta(\mathbf{r})$ , Near  $T_c$

$$S = -\mu^2 |\Delta|^2 + \lambda |\Delta^2|^2 + |\nabla \Delta(\mathbf{r})|^2$$

$$\frac{\langle \Delta N^2 \rangle}{\langle N \rangle} = \frac{1}{\beta} \frac{1}{\langle N \rangle} \frac{\partial \langle N \rangle}{\partial \mu} = \frac{1}{\beta \langle N \rangle} \frac{\partial \ln Z}{\partial \mu} ; d\mu = \mu - d\mu \text{ at fixed } \dots$$

$$\Delta \rightarrow \Delta e^{i\chi(n)}$$

$$\langle \psi(n) \psi(n') \rangle$$

$$\begin{pmatrix} N_0 & \Delta \\ \Delta^* & -N_0^* \end{pmatrix} \rightarrow \text{Spur}$$

$$+ \Delta(n) V(n) \text{ where } \Delta(n) = V \langle \psi(n) \psi(n) \rangle$$

To describe flow

condensate  $u_x, v_x \neq 0$  is her



$$\Delta(r) = |\Delta| e^{2i\theta \cdot r}$$

$$E_h u_h = \sum_{k \neq h} t_{hk} u_k + |\Delta| e^{2i\theta \cdot r} v_k$$

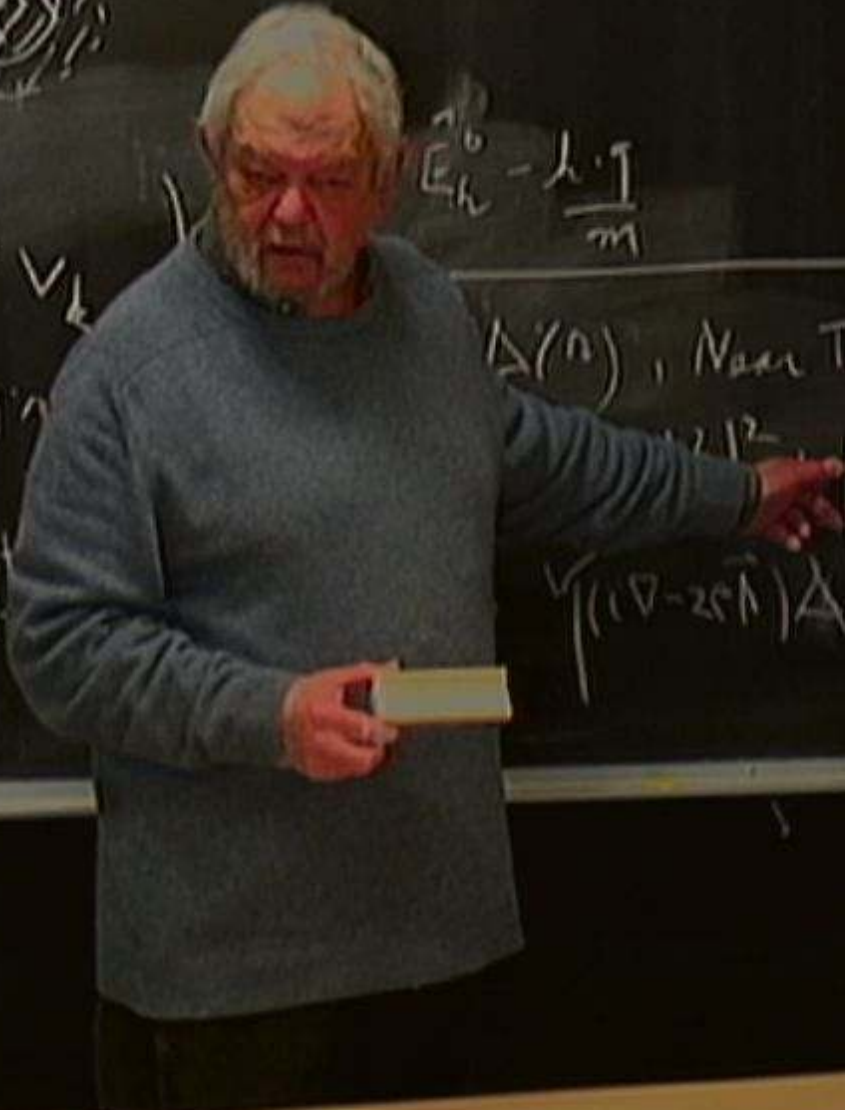
$$E_h v_h = - \sum_{k \neq h} t_{hk} v_k + |\Delta| e^{-2i\theta \cdot r} u_k$$

$$E_h = \frac{\sum_{k \neq h} t_{hk}}{h} + \left[ \frac{\sum_{k \neq h} t_{hk}}{h} \right]$$

$$E_h = \frac{h \cdot \eta}{m}$$

$\Delta(r)$ , Near  $T_c$

$$\sqrt{(\nabla - 2e\vec{A})\Delta}^2$$



$$\frac{\langle \Delta N^2 \rangle}{\langle N \rangle} = \frac{1}{\beta} \frac{1}{\langle N \rangle} \frac{\partial \langle N \rangle}{\partial \mu} = \frac{1}{\beta \langle N \rangle} \frac{\partial \ln Z}{\partial \mu}; \quad d\mu = \mu - d p \text{ at fixed } T$$

$$\Delta \rightarrow \Delta e^{i\chi(r)}$$

$$\langle \Psi(r) \Psi(r') \rangle$$

$$= \begin{pmatrix} N_0 & \Delta \\ \Delta^* & -N_0^* \end{pmatrix}^{-1} \text{Spur}$$

$$E = \begin{pmatrix} \Delta(r) V(r) \\ \Delta^*(r) U(r) \end{pmatrix} \text{ where } \Delta(r) = V \langle \Psi(r) \Psi(r) \rangle$$

$$\frac{\langle \Delta N^2 \rangle}{\langle N \rangle} = \frac{1}{\beta} \frac{1}{\langle N \rangle} \frac{\partial \langle N \rangle}{\partial \mu} = \frac{1}{\beta \langle N \rangle} \frac{\partial \langle N \rangle}{\partial \mu} ; d\mu = \mu - d p \text{ at fixed } T$$

$$\Delta e^{iX} \chi(n) \text{ cov. } \psi \rightarrow e^{iX} \psi$$

$$\langle \psi(n) \psi(n') \rangle$$

$$= \begin{pmatrix} \chi_0 & \Delta \\ \Delta^* & -\chi_0^* \end{pmatrix}^{-1} \text{ Necessarily } \uparrow \uparrow \text{ Spur}$$

$$d\mu = 2e \Delta$$

$$E \psi(n) + \Delta^* \psi(n) \text{ where } \Delta(n) = V \langle \psi(n) \psi(n) \rangle$$

$$\frac{\langle \Delta N^2 \rangle}{\langle X \rangle} = \frac{1}{\beta} \frac{1}{\langle N \rangle} \frac{\partial \langle N \rangle}{\partial \mu} = \frac{1}{\beta \langle N \rangle} \frac{\partial \langle N \rangle}{\partial \mu} ; d\mu = \mu - d\mu \text{ at fixed } \dots$$

$$\Delta \rightarrow \Delta e^{iX(n)} \text{ cov. } \psi \rightarrow e^{-iX} \psi$$

$$[D_n - 2eA] \Delta \Big|_2$$

where under X term

$$\langle \psi(n) \psi(n') \rangle$$

Necessity of spin

$$= \begin{pmatrix} \chi_0 & \Delta \\ \Delta^* & -\chi_0^* \end{pmatrix}$$

$$E \psi(n) = \Delta(n) V(n) \psi(n) + \Delta^* \psi(n)$$

where  $\Delta(n) = V \langle \psi(n) \psi(n) \rangle$

$$\frac{\langle \Delta N^2 \rangle}{\langle N \rangle} = \frac{1}{\beta} \frac{1}{\langle N \rangle} \frac{\partial \langle N \rangle}{\partial \mu} = \frac{1}{\beta \langle N \rangle} \frac{\partial \langle N \rangle}{\partial \mu} ; d\mu = \mu - d\mu \text{ at fixed } \dots$$

$$\Delta \rightarrow \Delta e^{i\chi(r)} \text{ with } \psi \rightarrow e^{i\chi} \psi$$

$$| [\partial_n - ieA] \Delta |^2$$

where under  $\chi$  term

$$\vec{A} \rightarrow \vec{A} + \frac{1}{2e} \vec{\nabla} \chi$$

$$\langle \psi(r) \psi(r') \rangle = \begin{pmatrix} \chi_0 & \Delta \\ \Delta^* & \chi_0^* \end{pmatrix}^{-1}$$

$$\begin{pmatrix} \chi_0 & \Delta \\ \Delta^* & \chi_0^* \end{pmatrix}^{-1} = \begin{pmatrix} \chi_0^{-1} + \Delta(n) V(n) & -\Delta(n) \\ -\Delta^*(n) & \chi_0^{-1} \end{pmatrix} \text{ where } \Delta(n) = V \langle \psi(n) \psi(n) \rangle$$

$$\frac{\langle \Delta N^2 \rangle}{\langle N \rangle} = \frac{1}{\beta} \frac{1}{\langle N \rangle} \frac{\partial \langle N \rangle}{\partial \mu} = \frac{1}{\beta \langle N \rangle} \frac{\partial \langle N \rangle}{\partial \mu} ; d\mu = \mu - d\mu \text{ at fixed } \dots$$

$$\Delta \rightarrow \Delta e^{i\chi(r)} \text{ cov. } \psi \rightarrow e^{i\chi} \psi \quad (\text{r} \downarrow)$$

$$\left| \left[ \vec{D}_n - 2eA \right] \Delta \right|^2$$

where under  $\chi$  term

$$\vec{A} \rightarrow \vec{A} + \frac{1}{2e} \vec{\nabla} \chi$$

$$\langle \psi(r) \psi(r') \rangle$$

$$= \begin{pmatrix} \mathcal{H}_0 & \Delta \\ \Delta^\dagger & \mathcal{H}_0^\dagger \end{pmatrix} \text{ Necessarity of } \uparrow \uparrow \text{ spin}$$

$$\begin{pmatrix} \mathcal{H}_0 & \Delta \\ \Delta^\dagger & \mathcal{H}_0^\dagger \end{pmatrix} + \Delta(r) V(r) \text{ where } \Delta(r) = V \langle \psi(r) \psi(r) \rangle$$

$$\frac{\langle \Delta N^2 \rangle}{\langle N \rangle} = \frac{1}{\beta} \frac{1}{\langle N \rangle} \frac{\partial \langle N \rangle}{\partial \mu} = \frac{1}{\beta \langle N \rangle} \frac{\partial \ln Z}{\partial \mu} ; d\mu = \mu - d p \text{ at fixed } T$$

$$\Delta \rightarrow \Delta e^{i\chi(r)} \text{ cov. } \psi \rightarrow e^{i\chi} \psi \quad (r \downarrow)$$

$$\left| \left[ i\partial_t - 2eA \right] \Delta \right|^2 + \left( \partial_r A_r \right)^2$$

where under  $\chi$  term

$$\vec{A} \rightarrow \vec{A} + \frac{1}{2e} \vec{\nabla} \chi$$

$$\langle \psi(r) \psi(r') \rangle$$

$$= \begin{pmatrix} N_0 & \Delta \\ \Delta^* & -N_0^* \end{pmatrix} \rightarrow \text{Narrowband } \rightarrow \text{Spur}$$

$$\begin{pmatrix} \psi(r) \\ \psi(r') \end{pmatrix} + \Delta(r) V(r) \text{ where } \Delta(r) = V \langle \psi(r) \psi(r') \rangle$$

$$\frac{\langle \Delta N^2 \rangle}{\langle N \rangle} = \frac{1}{\beta} \frac{1}{\langle N \rangle} \frac{\partial \langle N \rangle}{\partial \mu} = \frac{1}{\beta \langle N \rangle} \frac{\partial \ln Z}{\partial \mu}; \quad d\mu = \mu - d\mu \text{ at fixed } \dots$$

$$\Delta \rightarrow \Delta e^{i\chi(r)} \quad \text{cov. } \psi \rightarrow e^{i\chi} \psi \quad (r \downarrow)$$

$$\left| \left[ i\partial_n - zeA \right] \Delta \right|^2 + \left( \partial_n A_n \right)^2$$

$$\langle \psi(r) \psi(r') \rangle$$

$$= \begin{pmatrix} \chi_0 & \Delta \\ \Delta^* & -\chi_0^* \end{pmatrix} \rightarrow \text{Narrowband } \rightarrow \text{Spur}$$

where under  $\chi$  term

$$\vec{A} \rightarrow \vec{A} + \frac{1}{ze} \vec{\nabla} \chi$$

$$\begin{pmatrix} \chi_0 & \Delta \\ \Delta^* & -\chi_0^* \end{pmatrix} + \Delta(r) V(r) \quad \text{where } \Delta(r) = V \langle \psi(r) \psi(r') \rangle$$