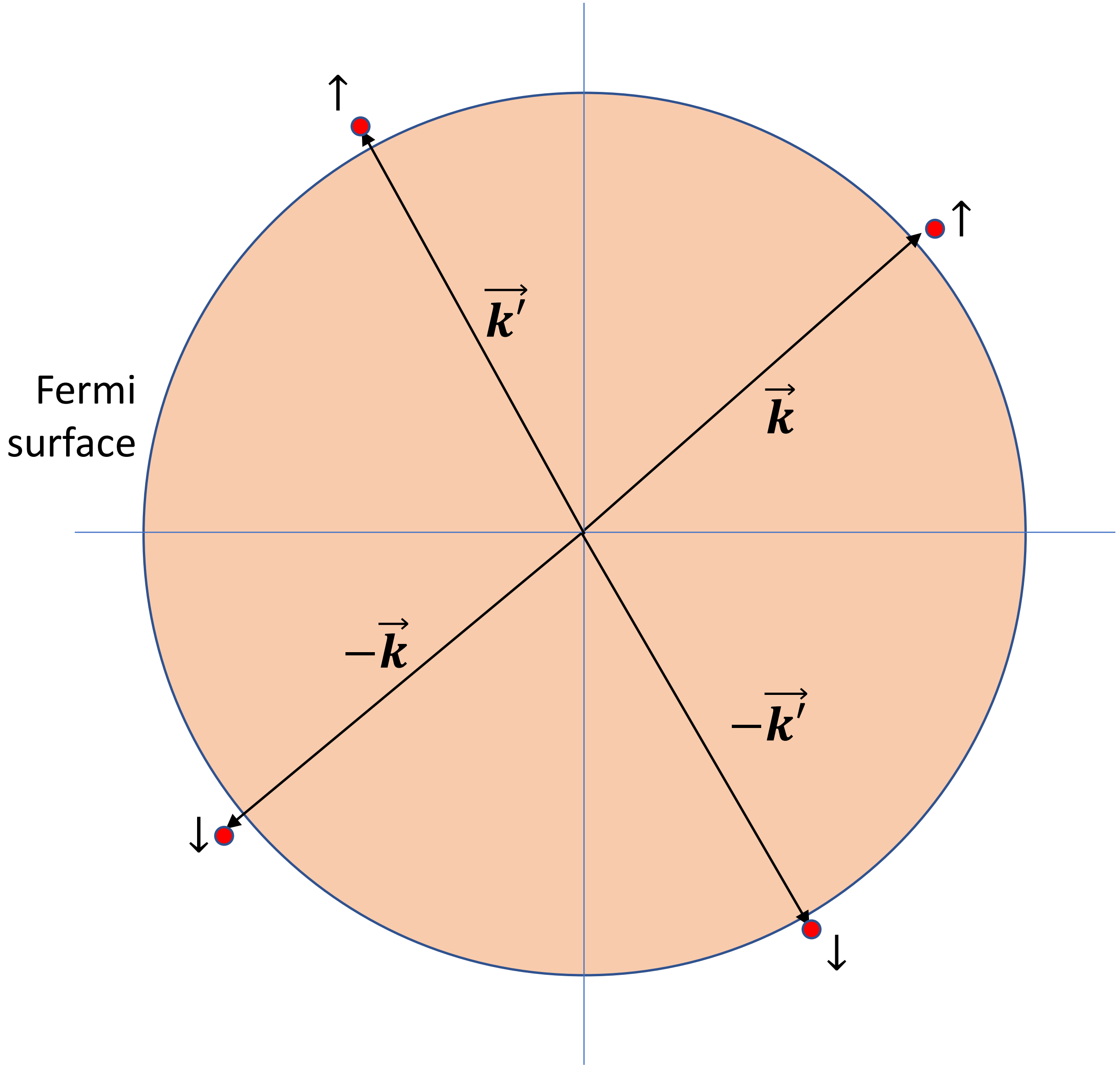
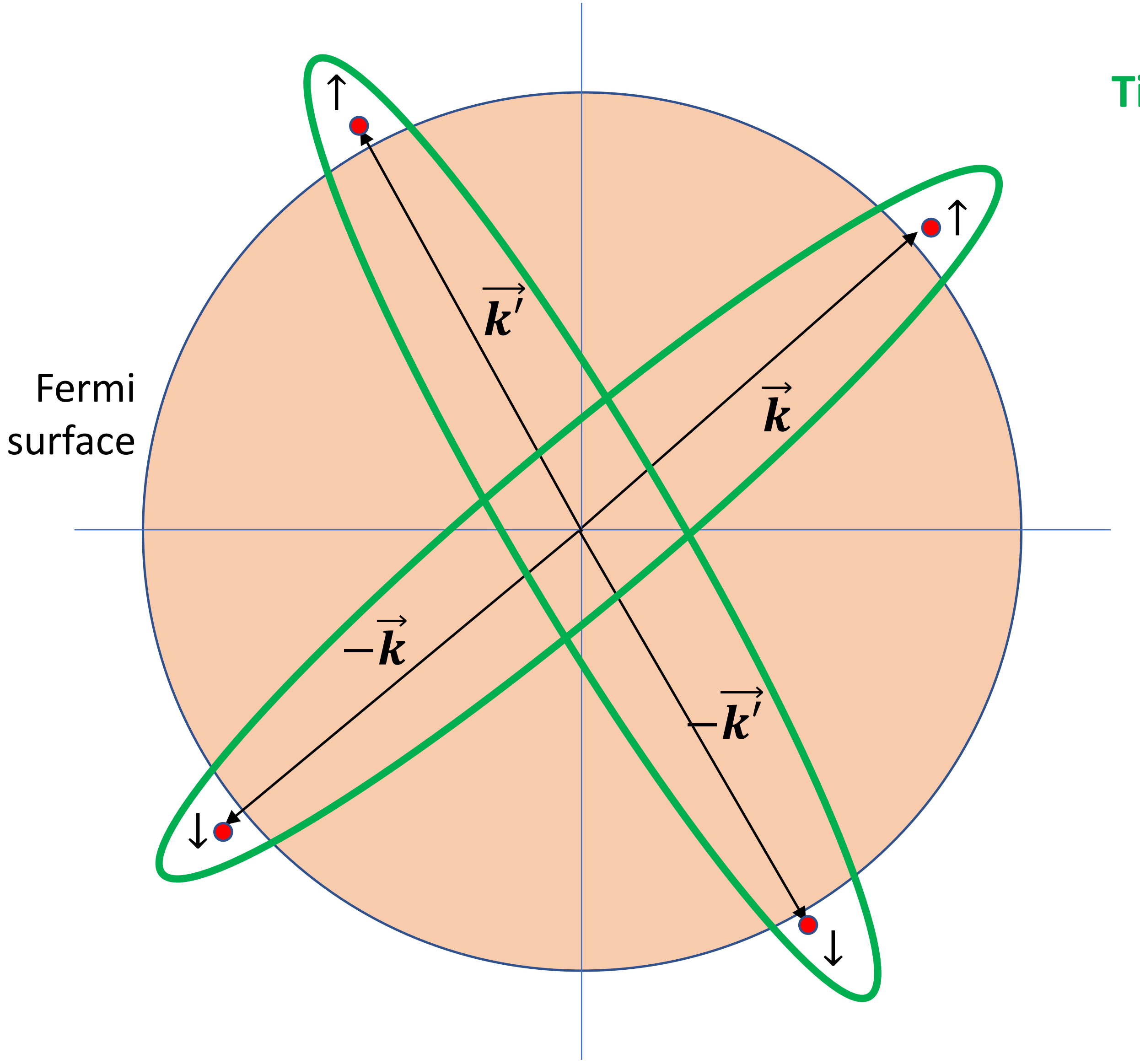
Two Cooper Pairs



Pairing of Time-Reversed States



Time-reversed states

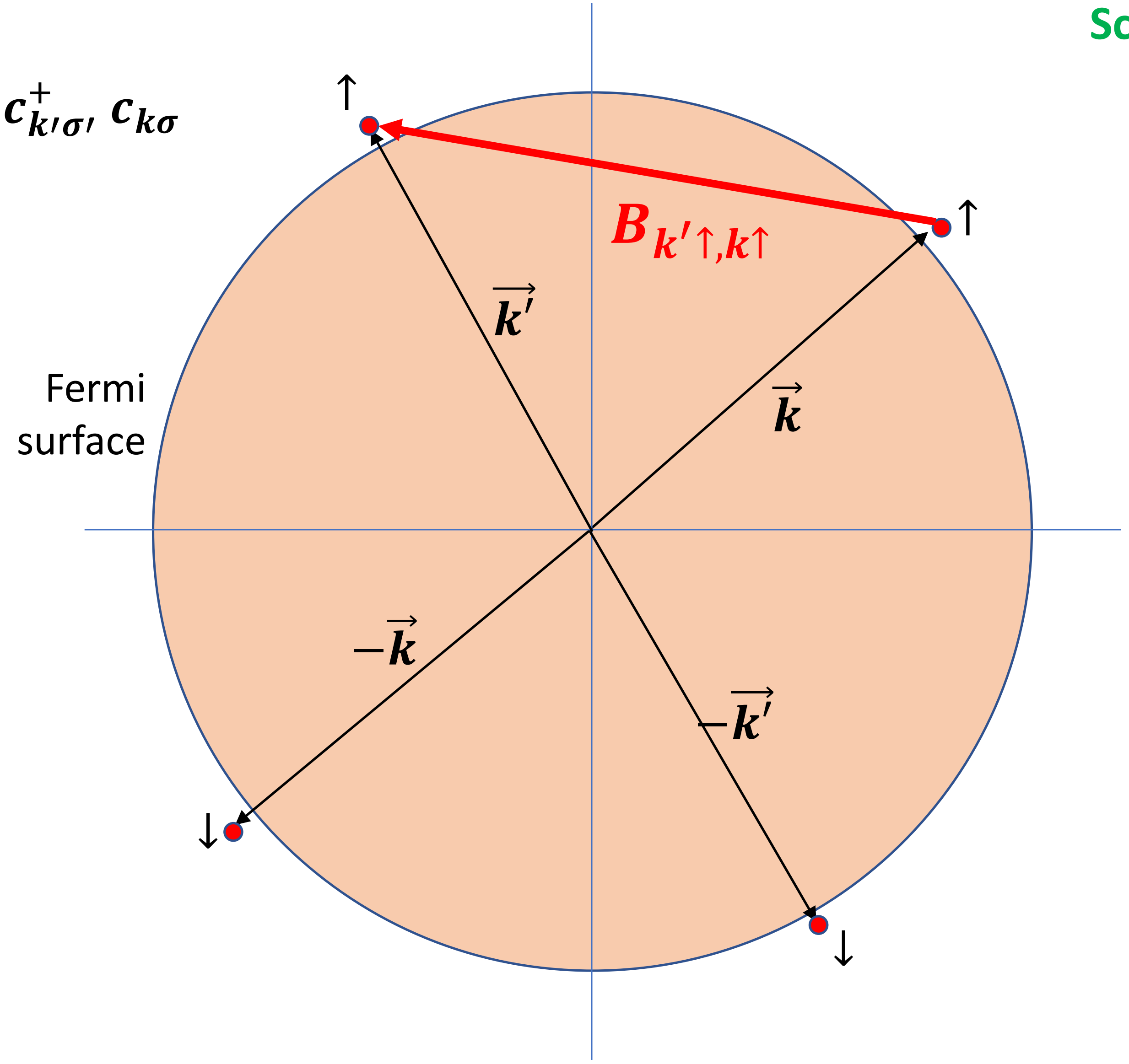
$$\hat{T}\,\vec{k} \rightarrow -\vec{k}$$

$$\hat{T} \uparrow \rightarrow \downarrow$$

Pairing of time-reversed states: P. W. Anderson, "Theory of Dirty Superconductors," J. Phys. Chem. Solids <u>11</u>, 26-30 (1959).

Scattering Between Single-Particle States due to Perturbation (I)

$$\mathcal{H}_{pert} = \sum_{k\sigma, k'\sigma'} B_{k'\sigma', k\sigma}\, c^{+}_{k'\sigma'}\, c_{k\sigma}$$



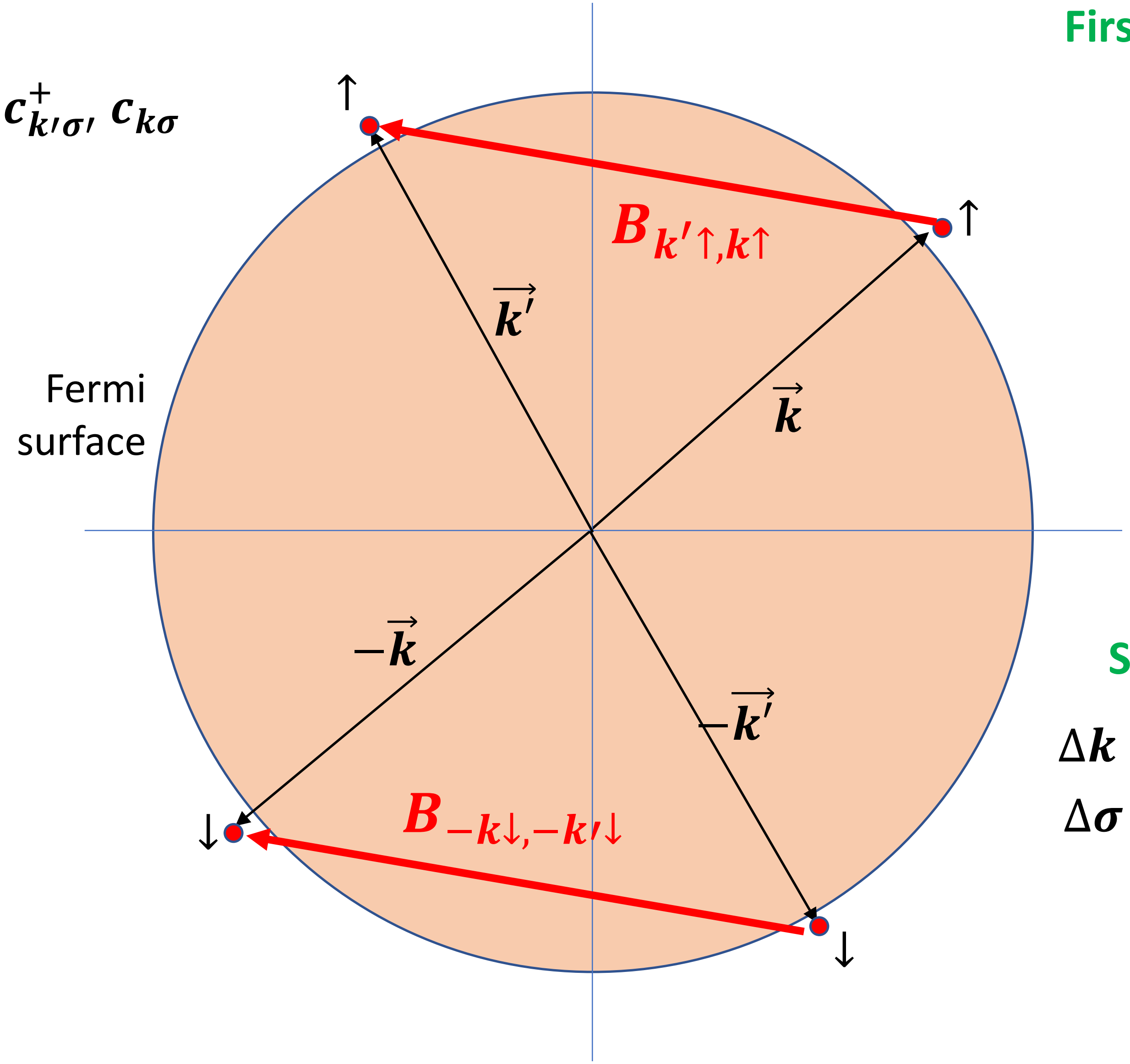
Scattering event

$$\Delta k = k' - k$$

$$\Delta\sigma = \sigma' - \sigma$$

Scattering Between Single-Particle States due to Perturbation (II)

$$\mathcal{H}_{pert} = \sum_{k\sigma,k'\sigma'} B_{k'\sigma',k\sigma}\, c^{+}_{k'\sigma'}\, c_{k\sigma}$$



First scattering event

$$\Delta \boldsymbol{k} = \boldsymbol{k}' - \boldsymbol{k}$$
$$\Delta \boldsymbol{\sigma} = \boldsymbol{\sigma}' - \boldsymbol{\sigma}$$

Consider another term in the sum …

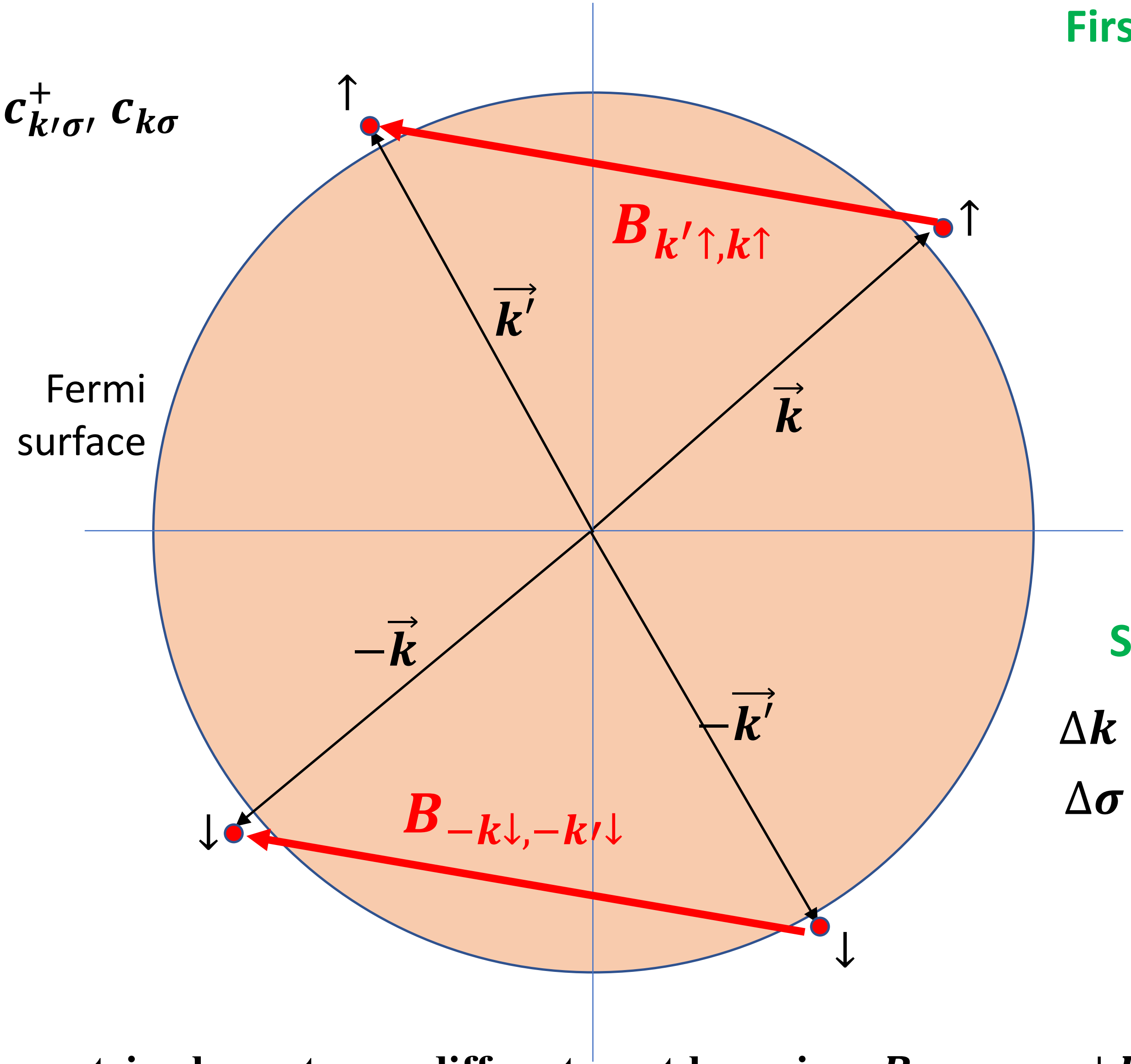
Second scattering event

$$\Delta \boldsymbol{k} = -\boldsymbol{k} - (-\boldsymbol{k}') = \boldsymbol{k}' - \boldsymbol{k}$$
$$\Delta \boldsymbol{\sigma} = -\boldsymbol{\sigma} - (-\boldsymbol{\sigma}') = \boldsymbol{\sigma}' - \boldsymbol{\sigma}$$

The <u>same momentum transfer and the same change in spin state occurs</u>, due to the correlated nature of the Cooper pairs in the original states

Scattering Between Single-Particle States due to Perturbation (III)

$$\mathcal{H}_{pert} = \sum_{k\sigma,k'\sigma'} B_{k'\sigma',k\sigma}\, c^{+}_{k'\sigma'}\, c_{k\sigma}$$



First scattering event

$$\Delta k = k' - k$$

$$\Delta\sigma = \sigma' - \sigma$$

Second scattering event

$$\Delta k = -k - (-k') = k' - k$$

$$\Delta\sigma = -\sigma - (-\sigma') = \sigma' - \sigma$$

These two matrix elements can differ at most by a sign: $B_{k'\sigma',k\sigma} = \pm B_{-k-\sigma,-k'-\sigma'}$

depending on whether the perturbation is symmetric (case I) or anti-symmetric (case II) upon time-reversal of the <u>electronic</u> state

Scattering Between Single-Particle States due to Perturbation (IV)

$$\mathcal{H}_{pert} = \sum_{k\sigma, k'\sigma'} B_{k'\sigma', k\sigma}\, c^{+}_{k'\sigma'}\, c_{k\sigma}$$

$$= B_{k'\sigma', k\sigma}\, (c^{+}_{k'\sigma'}\, c_{k\sigma} \pm c^{+}_{-k-\sigma}\, c_{-k'-\sigma'}) + \ \dots$$

Case I (+): Ultrasonic attenuation, …

Case II (-): Electromagnetic absorption, nuclear spin relaxation, …

These groups of terms give rise to "coherence factors" in the calculation of absorption rates, etc.