Single Particle Properties with Scattering and Spin Mixing

Federov *et al.* [1] measured spin-resolved photoelectron energy and momentum for excitation from the surface band near the Fermi level in gadolinium. Their findings are consistent with an interpretation [2] that the dominant relaxation mechanism for majority-spin electrons is electron-phonon interactions, whereas for minority-spin electrons, it is spin-flip scattering by emission or absorption of magnons. Of course, the eigenstates in one-electron approximation do not have pure spin up or down orientation because there is mixing from the spin-orbit interaction. However, this does not prevent a qualitative analysis using language appropriate to spin eigenfunctions. One just has to clarify the meaning of such a language, and that is the purpose of this note.

Using the notation established in table 1, the Green's function for an electron in a ferromagnet can be written approximately as

$$\hat{G}^{-1} = (\omega - \epsilon_k + i/\tau_0)\hat{1} - (\Delta + i/\tau_1)\hat{\sigma}_z + \delta\hat{\sigma}_x. \tag{1}$$

Here the usual Pauli matrices are introduced because the Green's function is a 2×2 matrix in spin indices. It is necessary to invert this to get the Green's function whose imaginary part is the approximate content of the photoemission measurement. Using the familiar properties of the Pauli matrices, the inverse is

$$\hat{G} = \frac{(\omega - \epsilon_k + i/\tau_0)\hat{1} + (\Delta + i/\tau_1)\hat{\sigma}_z - \delta\hat{\sigma}_x}{(\omega - \epsilon_k + i/\tau_0)^2 - (\Delta + i/\tau_1)^2 - \delta^2}. \tag{2}$$

2Δ	exchange splitting
2δ	spin-orbit splitting
$1/\tau_>$	majority spin lifetime
$1/\tau_<$	minority spin lifetime
$1/\tau_0$	$\frac{1}{2}(1/\tau_> + 1/\tau_<)$
$1/\tau_1$	$\frac{1}{2}(1/\tau_> - 1/\tau_<)$

Table 1: definition of symbols

The lower band (also the lower component of the two-component spin vector) is the majority or up spin, and the photoemission experiment measures approximately $-\Im G_{22}(k,\omega)$. We can write the 22-component of G as

$$G_{22} = \frac{1}{(\omega - \epsilon_k + i/\tau_0) + (\Delta + i/\tau_1) - \frac{\delta^2}{(\omega - \epsilon_k + i/\tau_0) - (\Delta + i/\tau_1)}} \tag{3}$$

The resonance occurs approximately at $\omega = \epsilon_k - \Delta$ and has width $1/\tau_0 + 1/\tau_1$ which is the majority-spin lifetime $1/\tau_>$ computed for a pure spin-up state. There is a correction to the resonant denominator. At the appproximate resonant energy, the correction is $\delta^2/(2\Delta - i/\tau_<)$ which is small (compared with the spin splitting 2Δ) for typical parameters of a strong ferromagnet like gadolinium.

The equations above provide a justification for using the language of pure spin eigenstates to discuss relaxation. Even though the true single-particle states have mixed-spin character, the self-energy from phonon or magnon exchange is diagonal in spin channels. When spin mixing is not too great ($\delta \ll \Delta$) the pure spin relaxation rates apply directly. If the weak-mixing approximation fails, equations like those above show how to use pure spin-relaxation rates in a mixed-spin situation.

References

[1] A. V. Fedorov, T. Valla, F. Liu, P. D. Johnson, M. Weinert, and P. B. Allen, "Spin-resolved photoemission study of photohole lifetimes in ferromagnetic gadolinium," Phys. Rev. B **65**, 212409 (2002).

[2] P. B. Allen, "Electron spin-flip relaxation by one magnon processes: Application to the gadolinium surface band," Phys. Rev. B **63**, 214410 (2001).