

Tjeng *et al.* Reply: In our Letter [1] we have reported a spin-resolved resonant photoemission study on Ni metal using circularly polarized light, which revealed the presence of $3d^8$ triplets at low energies extending all the way to the Fermi level, both below and above T_c . The orbital degeneracy of the $3d$ band and the Hund's rule splitting are therefore key elements for the understanding of Ni and other $3d$ ferromagnets. In the preceding Comment [2], van der Laan raises several objections concerning our interpretation of the experimental data. We will discuss these objections.

In his second paragraph, van der Laan states that the spin-resolved signal depends on even ground state moments and not on the spin or orbital moment. We have clearly stated in our Letter that this particular spectroscopic technique has the unique property that it measures the local $3d$ spin polarization *independent* of the *orientation* of the local moment, i.e., also in nonmagnetic isotropic materials. We have also provided an explanation using simple symmetry arguments. It is therefore implied, although we could have been more explicit on this point, that it is not $\langle \mathbf{M} \rangle$ which is being measured, but rather a quantity related to $\langle \mathbf{M}^2 \rangle$. So there is no disagreement with van der Laan on this point.

In the second and fourth paragraphs of the Comment, van der Laan claims that it is necessary to distinguish the resonant photoemission from the Auger decay signals for a correct interpretation of the data, and that this distinction is difficult to make. We disagree. In our experiment, the photon energy is chosen such that the intermediate state of the resonant photoemission process corresponds to the ground state of Ni in the presence of a $2p$ core hole. Whether the decay process is of the photoemission or of the Auger type is not relevant, since both are then degenerate. There is also no disagreement in the literature that the chosen intermediate state is primarily $2p^5 3d^{10}$, and that therefore the final state must be primarily $2p^6 3d^8$.

In the third and fourth paragraphs of the Comment, van der Laan states that the spectra are determined by atomic Coulomb, exchange, and spin-orbit interactions, and that therefore one should not expect to see a change across T_c . Moreover, van der Laan claims that the calculated atomic spectrum [3] provides a perfect agreement with our experimental results. While we agree that the high binding energy part of the spectrum is expected to be atomlike, we disagree completely that the low energy part, i.e., the region close to the Fermi level and the $3d$ band, can be described or understood using atomic theory alone. Indeed, the calculations of van der Laan fail to reproduce the intensity in the first 3 eV of the spectrum. And we find experimentally that this is where the $3d^8$ triplets are, extending all the way to the Fermi level. In fact, to claim that atomic theory should do well corresponds to ignoring the essence of the Ni problem or, for that matter, of other $3d$ ferromagnets, i.e., the question of whether or not the

atomic Hund's rule correlations survive the strong band formation, both below and above T_c .

In the first and fourth paragraphs, van der Laan claims that we have not demonstrated the presence of $3d^8$ in the ground state, and that other techniques are better suited. We would like to remark that the issue of the study is whether or not Hund's rule is effective, i.e., whether the $3d^8$ states that are present in the ground state are of *triplet* or *singlet* character, and not so much whether the $3d^8$ are there. That $3d^8$ states are present is not a point of discussion, since this can be expected and understood using both one-particle and many-body approaches, although the distribution of the occupied $3d^n$ ($n = 10, 9, 8, 7, \dots$) configurations will deviate from the binomial (statistical) distribution function in the presence of electron correlation effects. In fact, the 18% occupation for $3d^8$ in the ground state found in a many-body analysis by van der Laan [4] does not deviate too much from the one-particle binomial value of 15% [5], using van der Laan's value of 9.19 for the average $3d$ occupation. Surely we all agree that there is band formation of some sort, so a purely atomic representation cannot describe the eigenstates, and consequently the $3d^8$ states will always be present. Our study therefore focuses on the *spin character* of the $3d^8$ states, and we remain with our conclusion that there are more triplets than singlets present in the ground state, since the triplet $3d^8$ spectral weight extends all the way to the Fermi level.

L. H. Tjeng,¹ F. M. F. de Groot,¹ G. A. Sawatzky,¹
B. Sinkovic,² N. B. Brookes,³ J. B. Goedkoop,³ R. Hesper,¹
S. Altieri,¹ E. Pellegrin,¹ and S. L. Hulbert⁴

¹Solid State Physics Laboratory, Materials Science Centre
University of Groningen
Nijenborgh 4

9747 AG Groningen, The Netherlands

²Department of Physics
University of Connecticut
2152 Hillside Road
Storrs, Connecticut 06269

³European Synchrotron Radiation Facility
B.P. 220
38043 Grenoble Cedex, France

⁴National Synchrotron Light Source
Brookhaven National Laboratory
Upton, New York 11973

Received 13 February 1998 [S0031-9007(98)06667-8]
PACS numbers: 75.10.-b, 75.20.En, 75.25.+z, 79.60.Bm

- [1] B. Sinkovic *et al.*, Phys. Rev. Lett. **79**, 3510 (1997).
- [2] G. van der Laan, preceding Comment, Phys. Rev. Lett. **81**, 733 (1998).
- [3] G. van der Laan and B. T. Thole, J. Phys. Condens. Matter **7**, 9947 (1995).
- [4] G. van der Laan and B. T. Thole, J. Phys. Condens. Matter **4**, 4181 (1992).
- [5] L. H. Tjeng *et al.*, Phys. Rev. B **48**, 13 378 (1993).