Influence of magnetic order on optical properties of the heavy-electron antiferromagnets

L. Degiorgi,* H. R. Ott,* G. Grüner, M. Dressel** and Z. Fisk†**
*Laboratorium für Festkoerperphysik, ETH-Zürich, CH-8093 Zürich, Switzerland
**Department of Physics, University of California at Los Angeles, Los Angeles, CA 90024
†Materials Science and Technology Division, Los Alamos National Laboratory, Los Alamos NM 87545

We discuss the influence of antiferromagnetic order on optical properties of several heavy-electron systems. We find different electrodynamic responses of local magnetic moment and itinerant heavy-electron antiferromagnets.

The electrodynamics of several heavy-electron metals have been explored in detail. However, significantly less is known about the electrodynamics of the magnetically-ordered states of these materials. Some prototype compounds, where antiferromagnetic order develops, are URu_2Si_2 (T_N = 17.5 K),[1] UPd_2Al_3 (T_N=

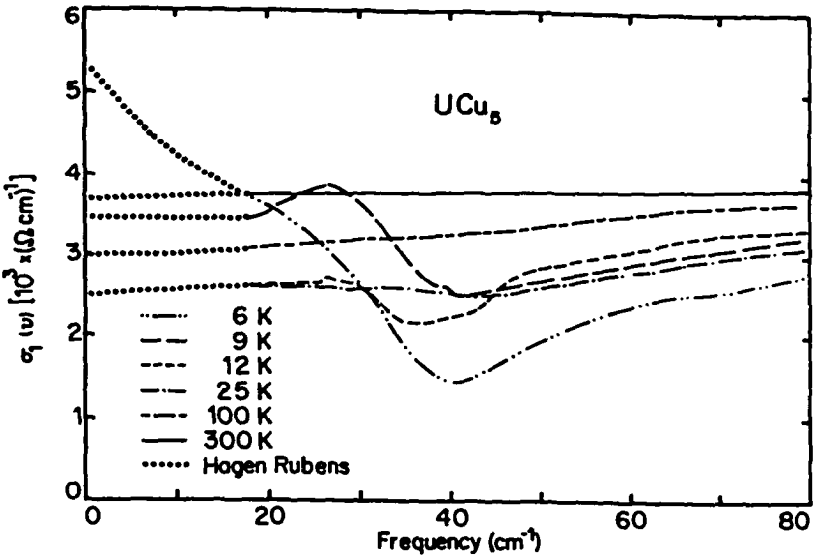

FIGURE 1. Optical conductivity of UCu_5 at several temperatures.

14 K),[2] U_2Zn_{17} (T_N= 9.5 K)[3] and UCu_5 (T_N = 15 K).[4] The so called antiferromagnetic state can develop as the consequence of a Fermi-surface instability, and such spin density wave formation leads to a gap (or partial gap) $2\Delta = 3.52 k_B T_N$ at the Fermi level. A commensurate antiferromagnetic order, on the other hand, does not lead to a gap at the Fermi level for a partially filled band. We call the first case an itinerant, the second a local moment antiferromagnet. While magnetic properties such as the magnetic susceptibility may be similar in both cases, optical conductivity measurements may discriminate between the different types of antiferromagnetic order.

In this paper, we discuss our optical investigations on UCu_5, U_2Zn_{17} and URu_2Si_2. We have performed optical reflectivity measurements on a very broad frequency range, from the ultraviolet down to the far infrared (FIR), and as a function of temperature, using four spectrometers with overlapping frequency ranges. More details about the optical experiments and the sample preparation is given elsewhere.[5,6] The optical conductivity is obtained from the Kramers-Kronig (KK) transformations applied to the measured optical reflectivity, appropriately extrapolated.[6] Figures 1 to 3 summarize the excitation spectra in FIR at several temperatures above and below T_N for the three investigated compounds.

The absorption at about 30 cm^{-1}, clearly seen in UCu_5 at 9 K (Fig. 1), is the typical feature expected for a single particle gap and is due to a SDW formation,[7] consequently implying the itinerant nature of the antiferromagnetic phase transition

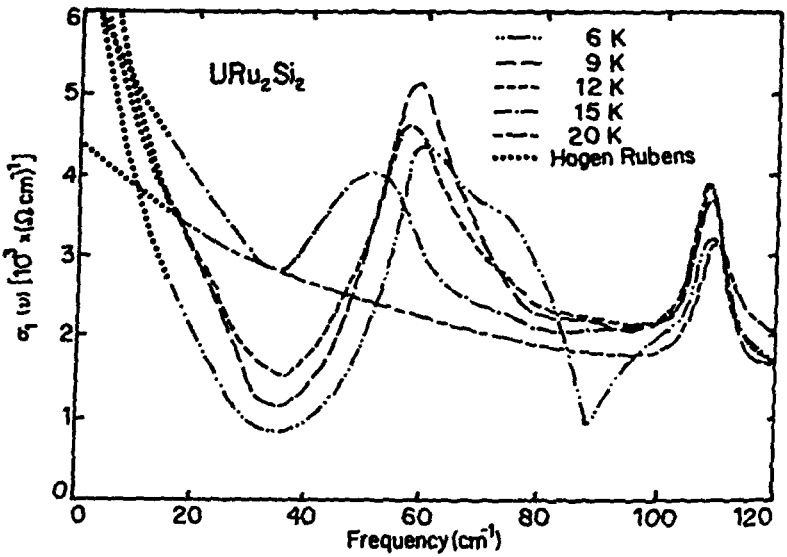

FIGURE 2. Optical conductivity of URu_2Si_2 at several temperatures.

at T_N. This is in agreement with an analysis of ρ (T) around T_N, employing a two component approach.[8] This latter analysis also suggests that only 20% of the total charge-carrier concentration above T_N is involved in the SDW phase transition. The remaining free charge-carrier (i.e., $\sim$ 80%) contribute to the optical conductivity with the low frequency Drude behaviour. This contribution overlaps with the SDW gap absorption (i.e., except at 6 K, the resistivity is large and the relaxation time τ small, so that $1/\tau$ >30 cm^{-1} where the gap appears). These conclusions are even more compelling in the case of Uru_2Si_2 (Fig. 2). Below T_N, a clear absorption between 40 and 60 cm^{-1} (corresponding to a reduced gap ratio of $2\Delta/k_BT_N$ = 3-5) is identified and, in accord with a previous optical investigation,[9] is ascribed to a SDW gap, in analogy also to the situation in Cr.[10] However, the antiferromagnetic transition in URu_2Si_2 appears well within the coherent many-body state where the remaining free (and heavy) charge carriers have already a small scattering rate, and the low-frequency renormalized Drude resonance is well separated from the SDW gap absorption at all temperatures below T_N.[9]

The gap features observed in UCu_5 and URu_2Si_2 is absent in U_2Zn_{17} (Fig. 3). In fact, there is not any clear indication of an absorption which appears in coincidence with T_N. Therefore, we ascribe U_2Zn_{17} to the class of materials with an antiferromagnetic phase transition characterized by a commensurate order of local magnetic moments [6]. The electrodynamic response of U_2Zn_{17} is similar to our recent experimental findings on UPd_2Al_3,[5] where no gap was found.

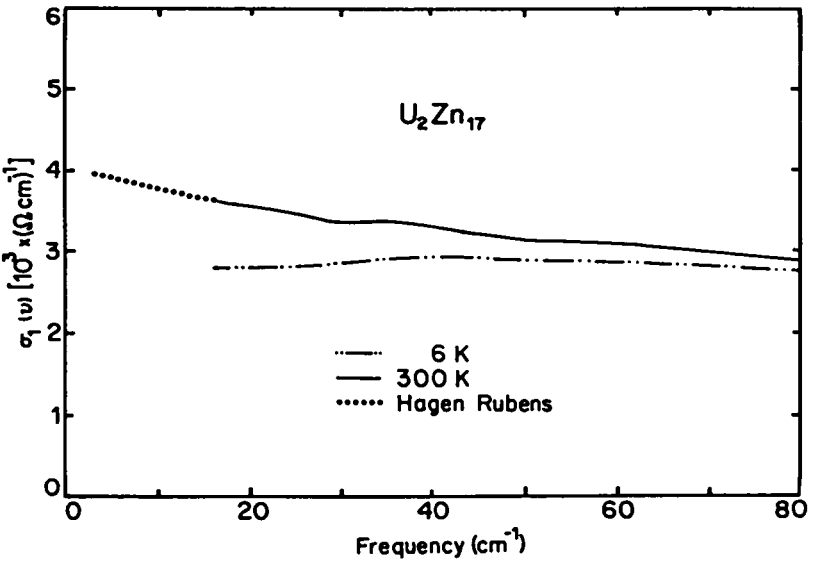

FIGURE 3. Optical conductivity of U_2Zn_{17} above and below T_N.

Finally, we note the correspondence between the scenario suggested by the optical properties in FIR and the behaviour of the transport properties. A clear anomaly in $\rho(T)$ at T_N is seen for the antiferromagnets of itinerant type, with increasing $\rho(T)$ giving evidence for a partial removal of the Fermi surface. This must be contrasted with the decrease of $\rho(T)$ at T_N by the local magnetic moment antiferromagnets, due to the reduction of the spin-flip scattering. Nonetheless, the relation to the magnetic structures is not clear at present and it remains to be seen whether incommensurate or commensurate magnetic order ought to be associated to UCu_5 and URu_2Si_2, or to U_2Zn_{17} and UPd_2Al_3, respectively.

ACKNOWLEDGMENTS

The authors wish to thank P. Wachter for important financial support and T. M. Rice, R. Hlubina and R. Monnier for helpful discussions.

REFERENCES

1. T. T. M. Palstra, A. A. Menovsky and J. A. Mydosh, Phys. Rev. **B33**, 6527 (1986).
2. C. Geibel, C. Schank, S. Thies, H. Kitazawa, C. D. Bredl, A. Boehm, M. Rau, A. Grauel, R. Caspary, R. Helfrich, U. Ahlheim, G. Weber and F. Steglich, Z. Phys. B-Cond. Matter **84**, 1 (1991).
3. H. R. Ott, H. Rudigier, P. Delsing and Z. Fisk, Phys. Rev. Lett. **52**, 1551 (1984).
4. H. R. Ott, H. Rudigier, E. Felder, Z. Fisk and B. Batlogg, Phys. Rev. Lett. **55**, 1595 (1985).
5. L. Degiorgi, M. Dressel, G. Grüner, P. Wachter, N. Sato, T. Komatsubara, Europhys. Lett., in print.
6. L. Degiorgi, H. R. Ott, M. Dressel, G. Grüner and Z. Fisk, in preparation.
7. A. W. Overhauser, Phys. Rev. **128**, 1437 (1962).
8. A. Bernasconi, M. Mombelli, Z. Fisk and H. R. Ott, Z. Phys. B, in print.
9. D. A. Bonn, J. D. Garrett and T. Timusk, Phys. Rev. Lett. **61**, 1305 (1988).
10. A. S. Barker Jr., B. I. Halperin and T. M. Rice, Phys. Rev. Lett. **20**, 384 (1968).