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Optical investigations of the electrodynamics of UPd_2Al_3

M. Dressel[a,*], L. Degiorgi[b], G. Grüner[a], P. Wachter[b], N. Sato[c], T. Komatsubara[c], Y. Uemura[d]

[a]*Department of Physics and Solid State Science Center, University of California, Los Angeles, CA 90024-1547, USA*
[b]*Laboratorium für Festkörperphysik, Eidgenössische Technische Hochschule, CH-8093 Zürich, Switzerland*
[c]*Department of Physics, Faculty of Science, Tohoku University, Sendai 980, Japan*
[d]*Department of Physics, Columbia University, New York, NY 10027, USA*

Abstract

We have investigated the electrodynamic response of UPd_2Al_3. At low temperatures, we observe the formation of a low-frequency narrow resonance, which indicates the development of the many-body coherent state. We do not find any evidence of a gap absorption associated to a spin density wave state below the antiferromagnetic phase transition at $T_N = 14$ K, which would develop as a consequence of a Fermi surface instability.

The heavy Fermion superconductor UPd_2Al_3 is one of the fascinating materials, besides URu_2Si_2 and UNi_2Al_3 [1, 2], showing the coexistence of both superconductivity and magnetic ordering [3]. The dc magnetic susceptibility exhibits a kink at $T_N = 14$ K and a remarkable drop at about $T_c = 2$ K, where also the specific heat shows clear anomalies.

The DC resistivity $\rho(T)$ shown in Fig. 1 bears a close similarity with the transport properties of other heavy Fermions. Above the broad maximum at $T_{co} = 80$ K, $\rho(T)$ decreases with increasing temperature in a manner similar to that observed in metals containing isolated magnetic impurities, suggesting a Kondo scattering mechanism. Below the coherence temperature T_{co}, where the many-body effects progressively develop, there is first the antiferromagnetic transition at $T_N = 15$ K, which reflects the freezing out of spin disorder scattering, and then a sharp drop to zero at the superconducting transition $T_c = 1.7$ K. While in URu_2Si_2 the antifer-

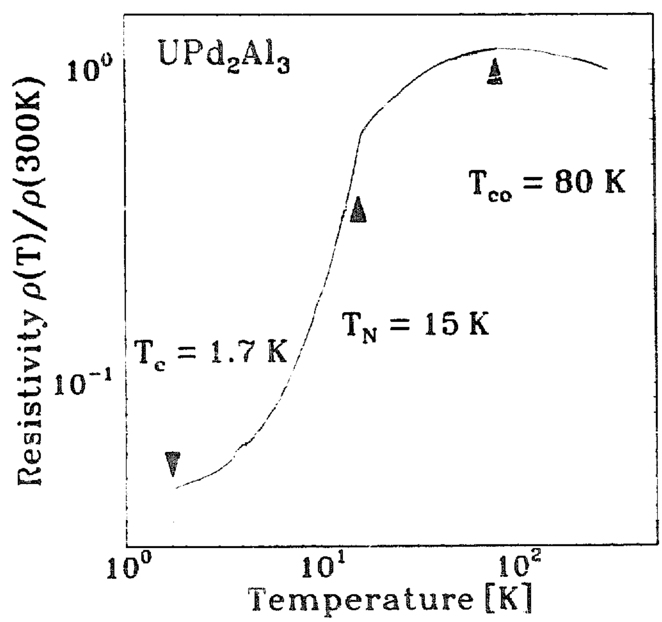

Fig. 1. Temperature dependence of the electrical resistivity of UPd_2Al_3 normalized to the room temperature value.

* Corresponding author.

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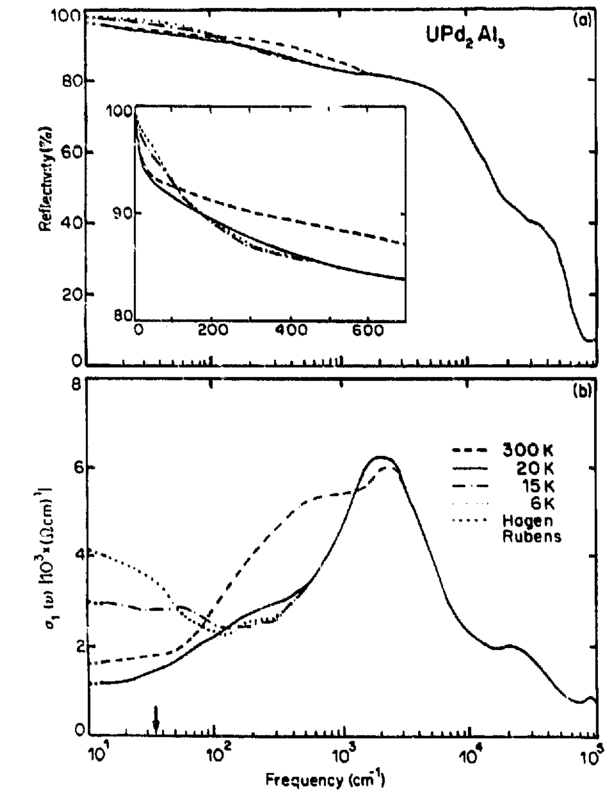

Fig. 2. (a) Reflectivity of UPd_2Al_3 at several temperatures in the entire frequency range. The inset displays the far infrared range of the reflectivity on an expanded scale. (b) Optical conductivity obtained through Kramers–Kronig transformation of the reflectance spectra. The arrow marks the expected position of the SDW gap $2\Delta = 3.53 k_B T_N$.

Table 1
Parameters of the renormalized Drude fit of the optical conductivity at different temperatures

	Plasma frequency $h\nu_p$ (eV)	Damping Γ_D (eV)	Effective mass m^*/m_b
$T = 300\ K > T_{co}$	4	0.025	1
$T = 15\ K < T_{co}$	0.754	0.025	27
$T = 6\ K < T_N$	0.47	0.007	67

romagnetic-like phase transition at 17.5 K shows up in a well-defined anomaly similar to the one at the spin density wave (SDW) transition in Cr, in UPd_2Al_3 we find only a change in slope of $\rho(T)$. The SDW-like transition in URu_2Si_2 corresponds to a nesting at $2k_F$ of the Fermi surface which directly affects the electronic density of states. Consequently, a transition across the single particle gap has been found in the excitation spectrum [4].

Besides the characterization of the samples by X-ray defraction, magnetization, d.c. and microwave resistivity experiments, we have investigated the optical reflectance on a broad frequency range between 14 and $10^5\ cm^{-1}$ at different temperatures (6–300 K). Figure 2(a) displays the optical reflectivity $R(\nu)$ at several significant temperatures above and below T_{co} and T_N, as well. The inset is a blow-up of the far infrared frequency range. The optical conductivity $\sigma_1(\nu)$ is obtained through a Kramers–Kronig transformation of $R(\nu)$ and shown in Fig. 2(b). Details are published elsewhere [5]. At 300 K we see a frequency-independent response at low frequencies and several absorptions at high frequencies due to interband transitions. At low temperatures in accordance with the crossover to higher reflectivity in the far infrared, we observe the formation of a temperature-dependent narrow Drude-like response.

In contrast to optical results on URu_2Si_2 [4], no absorption was found around $2\Delta = 3.53 k_B T_N = 35\ cm^{-1}$. This is, however, expected since the antiferromagnetic transition is commensurate with the lattice and it is not the consequence of the $2k_F$ nesting of the Fermi surface. Therefore, no SDW-gap opens at the Fermi level.

The only temperature dependence in $\sigma_1(\nu)$ is related to the temperature-dependent Drude-like resonance in the far infrared (Fig. 2(b)), ascribed to the optical conductivity of the heavy quasiparticle. The narrow resonance can be fitted with a renormalized Drude expression [6, 7]:

$$\sigma(\omega) = \frac{ne^2\tau^*}{m^*}\frac{1}{1 - i\omega\tau^*},$$

where m^* and τ^* are effective mass of the heavy quasiparticles and the renormalized scattering time, respectively. The parameters of the fit at different temperatures are listed in Table 1. Our results are in good agreement with estimations applying the Pippard formula [5], where the known values of the mean free path, the coherence length and the penetration depth are used [3]. We are also in accord with specific heat measurements and obtain the enhancement of the effective mass $m^* = 68 m_e$ and the total charge carrier concentration $n_c = 1.09 10^{22}\ cm^{-3}$.

In conclusion, we have measured the complete electrodynamic response of UPd_2Al_3 at temperatures above and below T_{co} and T_N. We do not find evidence of an absorption associated to a SDW energy gap, in accordance with the commensurate nature of the antiferromagnetic transition. At low temperatures, we do find a narrow resonance centered at $\omega = 0$ and can describe it with a renormalized Drude formula. We have extracted several intrinsic parameters characterizing this coherent many-body state, and found that the enhancement of the effective mass of the heavy quasiparticle is in perfect agreement with the thermodynamic results.

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