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FAR INFRARED OPTICAL PROPERTIES OF HEAVY FERMION SUPERCONDUCTORS: UBe_{13} AND URu_2Si_2

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We present far infrared reflectance measurements of UBe_{13} and URu_2Si_2 down to a temperature of 2 K. At low temperatures the optical conductivity of both materials may be described in terms of free charge carriers with frequency and temperature dependent scattering rates and mass enhancements. The 'coherent regime' occurs at too low a temperature in UBe_{13} to be observed in our measurements, but it can be observed in URu_2Si_2. In addition to the behaviour of the charge carriers URu_2Si_2 exhibits two strong phonon lines at 109 cm^{-1} and 378 cm^{-1} and below the magnetic transition temperature there is an additional absorbtion feature near 50 cm^{-1} .

URu_2Si_2 and UBe_{13} ,like most heavy fermion metals, have anomalous dc resistivities. Typically, as a sample is cooled the dc resistivity increases due to scattering of the conduction electrons by local magnetic moments. Then below a coherence temperature the resistivity drops rapidly. Along with the anomalous behaviour of the dc resistivity, both UBe_{13} and URu_2Si_2 have unusual far infrared optical properties. Drude theory, which models the electromagnetic response of free charge carriers with a frequency independent scattering rate, can not fully describe the far infrared spectrum of either of these metals. A simple extension of Drude theory allows for a frequency dependent scattering rate, $\Gamma(\omega)$, and an associated frequency dependent mass renormalization, $\lambda(\omega)$, which can be related to the imaginary and real parts of the electron self energy (1) . The expression for the optical conductivity then becomes:

$$\sigma(\omega) = \frac{1}{4\pi} \frac{{\omega_{\text{eff}}}^2}{\Gamma_{\text{eff}} - i\omega}$$

$$\text{where } \Gamma_{\text{eff}} = \frac{\Gamma(\omega)}{1+\lambda(\omega)} \text{ and } {\omega_{\text{eff}}}^2 = \frac{\omega_p^2}{1+\lambda(\omega)}$$

Fig. 1 shows the reflectance of UBe_{13} at four different temperatures above the coherence temperature. Overall, the reflectance decreases as the temperature is lowered, which is in qualitative agreement with the increase in dc resistance as the sample is cooled. The change in the reflectance below 100 cm^{-1} upon cooling from 8 K to 2 K is noteworthy because the dc resistivity increases rapidly when cooled through this temperature range (2) .

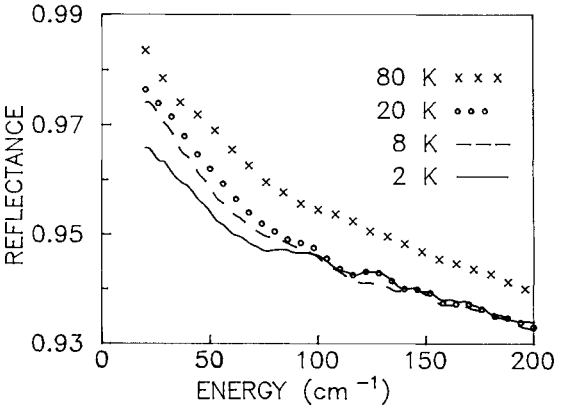

Figure 1. The far infrared reflectance of a polycrystalline sample of UBe_{13}.

Fig. 2 shows the real part of the optical conductivity of UBe_{13} , obtained by Kramers- Kronig analysis of the reflectance measurements. At 80 K the conductivity at the lowest frequency measured is 6300 $(\Omega\ \text{cm})^{-1}$ which is in reasonable agreement with the dc resistivity of 7700 $(\Omega\ \text{cm})^{-1}$ at this temperature. The discrepancy is most likely due to the high frequency extrapolations used to evaluate the Kramers- Kronig integral, although the conductivity may also rise somewhat at frequencies lower than the range of these measurements. The low frequency conductivity falls as the sample is cooled, in qualitative agreement with the temperature dependence of the dc conductivity. At all of the tem-

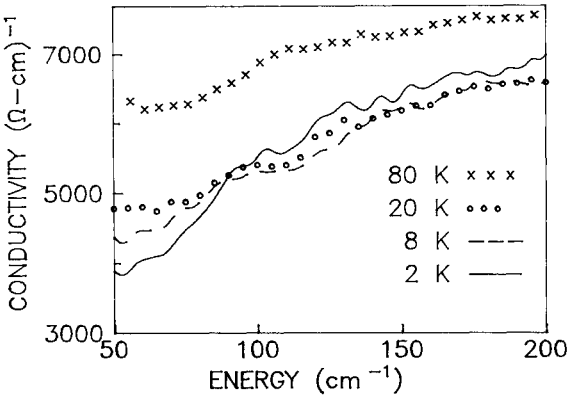

Figure 2. The real part of the optical conductivity of UBe_{13} obtained from Kramers-Kronig analysis of the reflectance data.

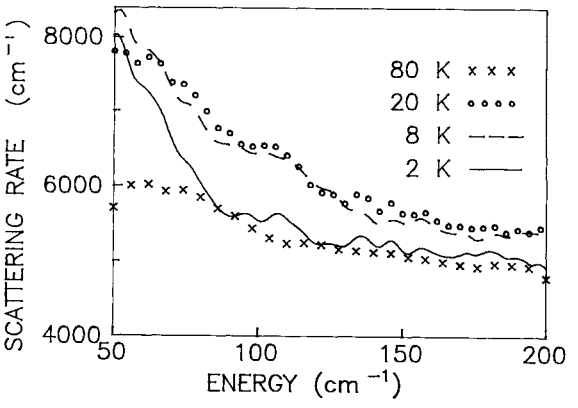

Figure 3. Frequency dependent scattering rate, $\Gamma(\omega)$, of charge carriers in UBe_{13}.

peratures measured the far infrared conductivity rises with increasing frequency and the rise becomes steeper at 2 K. Since Drude theory predicts a conductivity which decreases with increasing frequency, the optical properties of UBe_{13} can not be attributed to free carriers with a frequency independent scattering rate.

If the conductivity is analyzed in terms of a frequency dependent scattering rate, one obtains the result shown in fig. 3. The rising optical conductivity seems to be due to a scattering rate which decreases as the frequency increases and the energy scale of this feature is comparable to the width of the spin fluctuation scattering observed in neutron scattering measurements (3) . The rapid change in dc resistivity and far infrared reflectivity between 8 K and 2 K seems to be associated with a sharpening of this feature. Unfortunately our measurements do not extend to low enough temperatures to investigate the coherent regime in UBe_{13}.

Fig. 4 shows the reflectance of URu_2Si_2 both above and below its coherence temperature, which is at about 70 K (4) . At 90 K the reflectance is Drude-like with two strong phonon lines at 106 cm^{-1} and 378 cm^{-1}. The phonon at 106 cm^{-1} has also been observed in neutron scattering mmeasurements (5) . Below the coherence temperature the reflectance above 80 cm^{-1} is depressed and seems similar to the depressed reflectance seen above the coherence temperature in UBe_{13}. However, at longer wavelengths the reflectance of URu_2Si_2 below the coherence temperature is very different from any of the UBe_{13} reflectance spectra. At temperatures below 80 K the reflectance below 80 cm^{-1} rises to very high values and the development of this feature is coincident with the rapid drop in the dc resistivity of URu_2Si_2. This high reflectance is complicated by the development of a strong absorption feature near 50 cm^{-1} when URu_2Si_2 orders antiferromagnetically below 17.5 K.

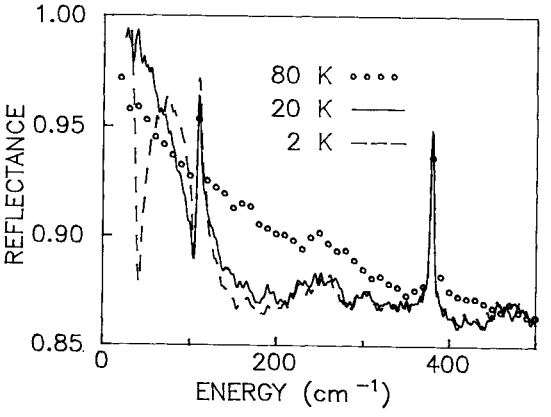

Figure 4. The reflectance of URu_2Si_2 measured with the electric field in the basal plane.

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