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OPTICAL PROPERTIES OF THE HEAVY FERMION SUPERCONDUCTOR UBe_{13} *

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Summary

We report on the optical properties of the heavy fermion superconductor UBe_{13} from 0.050 to 2 eV. The reflectance shows sharp structure at low frequencies superimposed on a smooth decrease down to 50% at 1.6 eV. The $ThBe_{13}$ compound is shown for comparison as a non-heavy fermion system. Kramers–Kronig analysis of reflectance measurements yields sharp interband structure in UBe_{13} in the 0.1 eV region. In the far IR, above 100 K, the material shows normal Drude behavior: the optical conductivity agrees well with the d.c. conductivity.

1. Introduction

The intermetallic compound UBe_{13} has attracted much interest because of its unusually high specific heat [1] at low temperatures, associated with electrons at the Fermi level that participate in the superconducting transition. The straightforward interpretation of this phenomenon is that the charge carriers have an effective mass of about 200 times the free electron mass. The uranium 5f electrons are assumed to have a very narrow bandwidth, but, in addition, further enhancements of the density of states may be caused by a cooperative transition that sets in below 2 K, just before the onset of superconductivity at 0.6 K. The magnetic susceptibility departs from a Curie–Weiss law at about 100 K [2] suggesting that spin fluctuations are the important low-lying excitations. Both magnetic neutron scattering [3] and Raman scattering [4] point to a spectrum of spin fluctuations with a half width of 14 meV.

The optical properties of these materials would be of interest for two reasons. The narrow bands associated with the high density of states at the

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Fermi level may show up as interband absorption structure in the conventional optical or near-IR region. Also the low lying states responsible for the low temperature cooperative phenomena may affect both the lifetime and the density of states of the electrons near the Fermi level modifying the Drude absorption of the free electrons.

In this paper we report on measurements of the optical reflectance of UBe_{13} over the range of wavelengths and temperatures relevant to the heavy fermion problem. A total spectral range from 0.050 to 2.0 eV is covered. In the spectral region from 0.085–2.0 eV we have performed measurements at room temperature only and in the far-IR range from 2 meV to 85 meV at a variety of temperatures ranging from 2 K to 100 K.

2. Experimental details

We used a polycrystalline sample of UBe_{13} in the form of a polished disk of 4 mm in diameter in the reflectance measurements. The reflected signal was compared with the signal from a metal mirror to obtain the reflectance. To correct for mechanical flaws in the polished surface and other geometric effects an additional reflectance measurement was made with aluminum evaporated onto the sample surface. The ratio of the previously measured reflectance to the reflectance of the sample with the aluminum was used. The absolute reflectance of our reference sample was obtained by means of a very accurate multiple-reflection technique. The measurements were performed with a grating spectrometer using a variety of sources and detectors.

3. Results and discussion

In Fig. 1 we show the reflectance of UBe_{13} and ThBe_{13} at room temperature in the range from 0.05 eV to 2.0 eV. As the reflectance drops from the high level in the IR in both materials it settles down to a value of about 50% at 1.5 eV energy.

The optical conductivity, which can be obtained by Kramers–Kronig transformation of the reflectance, is closely related to the interband absorption strength. To perform this transformation knowledge of the reflectance over a wide frequency range is necessary [5]. From 2 meV to 85 meV the reflectance values were obtained at low temperature by direct measurement, to be reported in a separate publication [6]. From 85 meV to the visible, room temperature grating spectrometer data were used. Outside these ranges of direct measurements we used various extrapolations. At low frequency it was possible to use the Hagen–Rubens expression [5]

$$R = 1 - \left(\frac{2\omega}{\pi\sigma} \right)^{1/2}$$

where σ is the d.c. conductivity. At 100 K the conductivity is Drude-like and extrapolates to a d.c. conductivity of $7600 (\Omega \text{ cm})^{-1}$ which is in good agreement

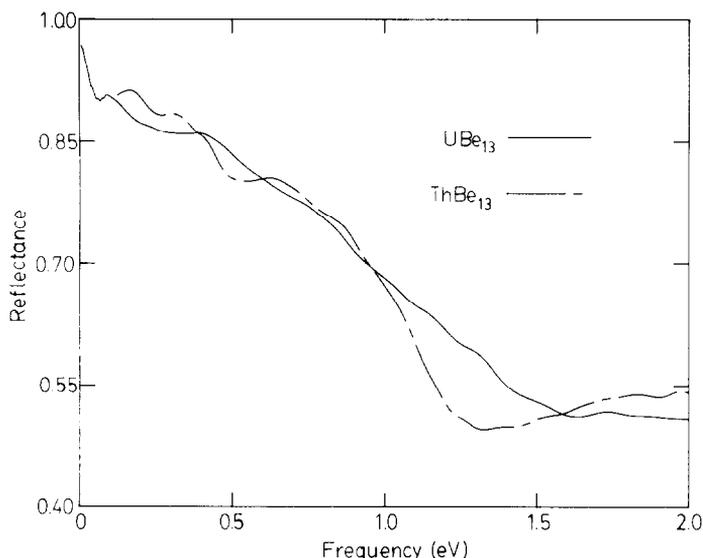


Fig. 1. The reflectance of UBe_{13} at 300 K (full curve) and ThBe_{13} (chain curve). The reflectance in the optical region is dominated by a broad minimum that starts at 1.5 eV.

with the measured value of $7700 (\Omega \text{ cm})^{-1}$ for our sample. Since we did not perform any UV measurements, high frequency extrapolations were also necessary. We based our extrapolation for both UBe_{13} and ThBe_{13} above 2.0 eV on the data of Eklund [7] up to 22 eV and beyond this point an analytic extrapolation for the reflectance proportional to ν^{-4} was used. Although somewhat arbitrary, this last extrapolation makes a relatively small contribution to the Kramers–Kronig integral and tends only to affect the absolute value of the optical constants in the IR, but does not substantially alter the structure. The magnitude of the conductivity in the visible is much more uncertain.

Figure 2 shows the high frequency optical conductivity calculated from the reflectance data for both UBe_{13} and ThBe_{13} . Using the sum rule for the optical conductivity one can estimate the number of electrons that participate in a given transition assuming an effective mass of unity. UBe_{13} has six uranium valence electrons *vs.* the 26 beryllium electrons in a formula unit; the uranium contribution to the overall oscillator strength would be expected to be five times smaller. A rough application of the sum rule shows that by 2 eV the oscillator strength corresponding to four electrons has been exhausted, principally by the sharp structure below 1 eV. Since beryllium metal itself has most of its interband optical oscillator strength at 5 eV and above [8–10] we associate the low-lying peaks in our spectra with the actinide atoms and assign the continuum above 1 eV to the beryllium 2s electrons.

While the beryllium spectrum is featureless at low frequencies (apart from the strong Drude tail), the UBe_{13} spectrum shows evidence of considerable interband structure below 1.0 eV, particularly prominent is the peak at 93 meV

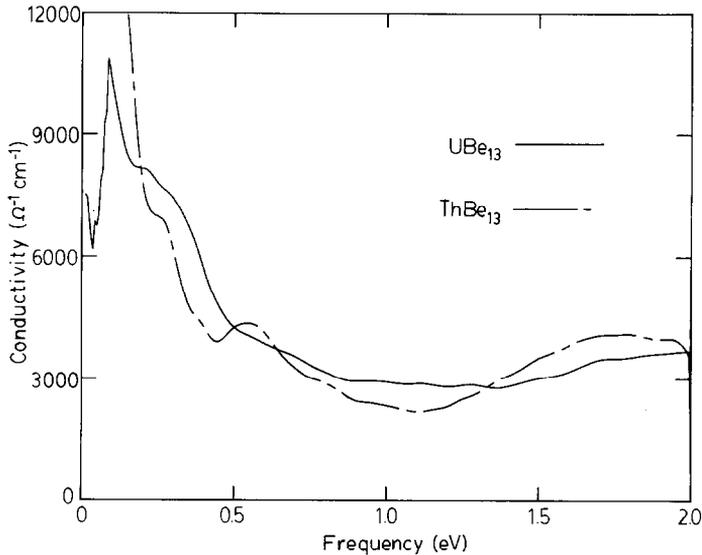


Fig. 2. The optical conductivity of UBe_{13} and ThBe_{13} at room temperature. There is an overall resemblance in the conductivities of the two actinides. The sharp low frequency structure starting at 95 meV we attribute to low lying states of the uranium electrons. There is excellent agreement between the d.c. conductivity and the low-frequency extrapolated optical conductivity of UBe_{13} .

along with a broader one at 295 meV. The 93 meV peak has full width of 50 meV and is quite narrow by the standards of interband transitions in metals. It is very reasonable to assign this peak to transitions between bands that are derived from the f states of the uranium atom. We have not examined the low frequency spectrum of ThBe_{13} in sufficient detail but it appears that in this material, too, there is evidence of interband transitions in the 0–1.0 eV range. It should be noted that optical transitions are proportional to a joint density of states; the individual bands could be narrower than the peaks seen here. The absolute position for the levels that are responsible for the 93 meV transitions is not known, all that we can say is that both the initial and the final states are within 93 meV of the Fermi level. The overall weak oscillator strength of the low lying structure is consistent with the idea that it is related to the three f electrons in the formula unit rather than the 28 s electrons.

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