Point-contact spectroscopy of the intermetallic valence-fluctuation compound $CeNi_5$ in the ballistic regime

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Point-contact spectra of a valence-fluctuation compound in the ballistic and diffusion regimes of electron transport have been obtained for the first time. The possibilities and distinctive features of point-contact spectroscopy for such compounds are demonstrated in the particular case of $CeNi_5$.

Valence-fluctuation compounds have been the subject of active research in recent years.[1] Although several studies of point contacts of such compounds have been reported (Ref. 2, for example), all these studies have been confined to the thermal regime for electron transport, in which Joule heating of the contact region is predominant. In this regime, it is not possible to determine the excitation energies directly from the measurements, as would be possible in the ballistic and diffusion regimes.[3]

Figures 1 and 2 show some point-contact spectra from our study of $CeNi_5$–$CeNi_5$ point contacts (curves 1). Shown for comparison are some results of our earlier study[4] of point-contact spectra of the isostructural compound $PrNi_5$–$PrNi_5$ in the ballistic regime ($l_i, l_{\varepsilon} > d$) and in the diffusion regime ($l_i < d < \sqrt{l_i l_{\varepsilon}}$) (curves 2; l_i and l_{ε} are the momentum and energy mean free paths of the electrons near the contact, and d is

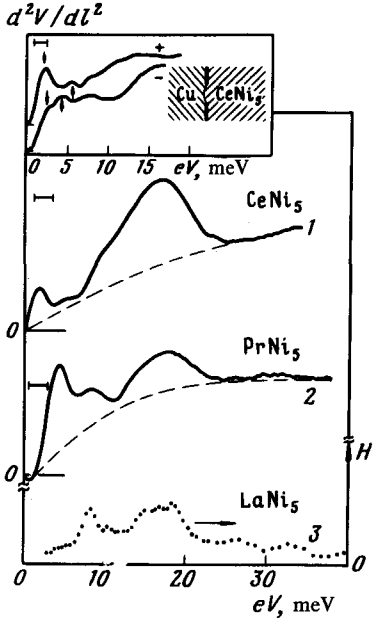

FIG. 1. The resistances R of the point contacts for spectra 1 and 2 are 12 and 11.5 Ω, respectively ($T = 4.2$ K). The inset shows the polarity of the $CeNi_5$ electrode ($R = 11$ Ω, $T = 1.7$ K); the arrows show nonphonon peaks. Horizontal bars—Energy resolution; dashed lines—assumed background.

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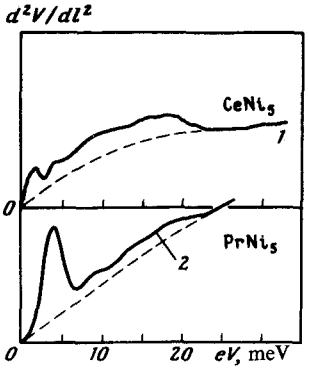

FIG. 2. The resistances R for spectra 1 and 2 are 6.4 and 7.6 Ω, respectively ($T = 1.7$ K).

the contact diameter). Figure 1 also shows results on $H(eV)$, which is similar to the phonon state density in $LaNi_5$, found by inelastic neutron scattering by Bührer *et al.*[5] (curve 3).

It can be concluded from a comparison of the relative intensities of the phonon peaks in the energy interval 7–22 meV in the point-contact spectra of $PrNi_5$ and $CeNi_5$ that the point-contact spectra of $CeNi_5$ also correspond to the ballistic regime (since there are intense phonon peaks on curve 1 in Fig. 1) and the diffusion regime (the intensity of the phonon peaks with respect to the background is lower in Fig. 2). In the thermal regime, phonon peaks would not be observed at all.

In the point-contact spectra of $CeNi_5$ there are, in addition to the phonon structure, which agrees well with the phonon part of the point-contact spectrum of $PrNi_5$ and the phonon state density in $LaNi_5$, two peaks at 1.8–2 and 4–5 meV.

These low-energy peaks cannot be attributed to excited states of the Ce^{3+} ion which arise from crystal-field effects, as they do for Pr^{3+} in $PrNi_5$ (the peaks at 4.5, 13.6, and 30 meV on curves 2 in Figs. 1 and 2). These peaks should be at 17 and 41 meV according to the calculations of Ref. 6, and *they should not depend* on the polarity of the $CeNi_5$ electrode in heterocontacts. In contrast with those predictions, we find that the relative intensity of these peaks in $CeNi_5$–Cu heterocontacts differ with the sign of the potential applied to the $CeNi_5$ electrode (see the inset in Fig. 1).

On the other hand, it follows from several measurements that $CeNi_5$ is a valence-fluctuation component, in which the energies of the Ce^{3+} ions with a single electron in the $4f$ shell and of the Ce^{4+} ions without a $4f$ electron (which has gone into the conduction band) are assumed to be approximately equal to each other and to the Fermi energy.[1]

Point-contact spectroscopy can be classified as a "fast" method for studying valence-fluctuation compounds, since the scale time of the interaction between an electron and the ions in the contact region is 10^{-15}–10^{-13} s. Charge fluctuation generally occurs over a longer time (10^{-13}–10^{-12} s for $CeNi_5$, as we will show below).

Figure 3 shows the electron distributions in energy (A) and in momentum space (C) in the central part of the point contact, which dominates the resistance of the

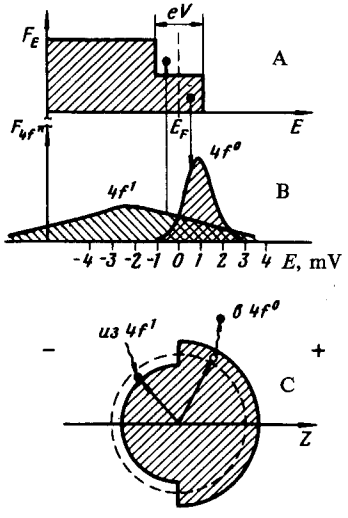

FIG. 3. Capture of electrons and holes by $4f$ levels in $CeNi_5$.

contact. Interestingly, in applying a voltage V to the electrodes we can shift part of the Fermi surface with respect to the unperturbed surface (shown by the dashed line in Fig. 3C). This shift is by an amount $eV/2v_F$ at the center of the contact and $\sim eV/v_F$ at the periphery. The contribution of the periphery to the resistance of the contact, however, falls off in proportion to $1/r^2$, where r is the distance from the center. Obviously, conduction electrons with an excess energy eV can be captured by Ce^{4+} ions to the $4f$ shell and be lost from the number of conduction electrons; this process makes an additional contribution to the resistance of the point contact. Holes, on the other hand, may be captured by Ce^{3+} ions, and this process will also contribute to the resistance of the contact, since an electron is emitted from the $4f$ shell with a momentum directed preferentially opposite the direction of the electron current in the contact.

In summary, the intensities and shapes of the peaks for heterocontacts should vary with the potential applied to the $CeNi_5$ electrode. This is precisely what we observe in our experiments, and we accordingly attribute the two low-energy peaks to the processes described above. When we take into account the thermal and modulational broadening of the peaks in these experiments, and if we assume that the unbroadened peaks have a Lorentzian shape, then for the peaks at 1.8–2 and 4–5 meV in the point-contact spectra the corresponding widths will be 1.5–2 meV and 6–8 meV, and the respective ion lifetimes will be $(3.3–4.3)\times 10^{-13}$ s and $(0.8–1.0)\times 10^{-13}$ s. The level scheme that we find is shown in Fig. 3B. Since the narrow peak is above the Fermi surface, it can logically be attributed to the Ce^{4+} ion. In this case the average valence that we find for the cerium ions in $CeNi_5$ from the peak widths is 3.77–3.84 (we are ignoring the broadening of the peaks in the point-contact spectra due to the different shift of the Fermi surface far from the contact).

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