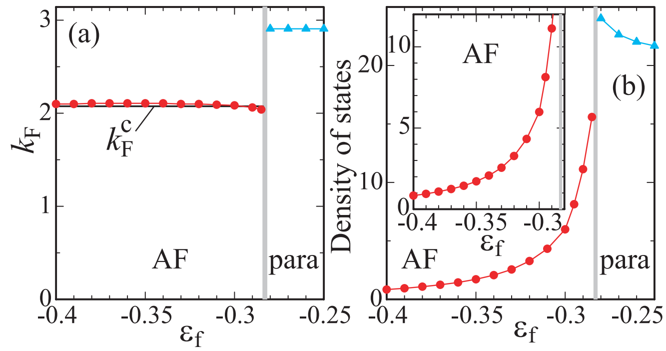

Fig. 3. (color online) (a) Fermi wavenumber k_F vs. ε_f in the AF state (circles) and the paramagnetic state (triangles) for $t = 1$, $V = 0.2$, $U = \infty$, $U_{fc} = 0.5$, and $h = 0.005$ at $n = 0.9$. The solid line represents k_F for the conduction band ε_k at $\bar{n}_c = 0.8$. (b) $D(\mu)$ vs. ε_f for the same parameters as (a). Inset is enlargement of the AF phase.

is quite consistent with the dHvA measurement that the dHvA frequencies, including the β_2 blanch, keep almost constant for $0 \le P < P_c$, and they suddenly jump at $P = P_c$ and remain constant for $P > P_c$.

We find that the measured enhancement of the effective mass of electrons from $m^* \sim 6m_0$ at $P = 0$ to $m^* \sim 60m_0$ at $P \to P_{c-}$[9] is also reproduced; The ε_f dependence of the density of states (DOS) at the chemical potential μ, $D(\mu)$, is shown in Fig. 3(b), where $D(\omega) \equiv \sum_{\mathbf{k}\sigma} \delta(\omega - E_{\mathbf{k}\sigma})/(2N)$ with $E_{\mathbf{k}\sigma}$ being the energy band of Eq. (1). The DOS is enhanced about 10 times when ε_f approaches ε_f^c, as shown in the inset of Fig. 3(b). However, the renormalization factor $\sqrt{Z_\sigma}$, due to the many-body effect, does not show divergent growth even as ε_f approaches ε_f^c. This implies that the divergent growth of the DOS is mainly due to the band effect. Then, $D(\mu)$ is proportional to m^* and $\sqrt{A}$, explaining the measured $\sqrt{A}/m^*$ =const. scaling.[11,28] We note that $D(\mu)$ at $\varepsilon_f = -0.4$ is about 10 times larger than the density of states of conduction electrons at $\bar{n}_c = 0.8$, $D_c(\mu) = 0.092$, which is also consistent with enhanced γ of $CeRhIn_5$[5] from that of $LaRhIn_5$[13,14] at $P = 0$. When ε_f increases, m_s decreases, as shown in Fig. 1(c). Since the increase in ε_f tends to increase the renormalization factor $\sqrt{Z_\sigma}$, the energy gap between the original lower-hybridized band and the folded band in the AF phase is increased. This effect pushes up the latter band in the 1st Brillouin zone, making the flat part of the band, mainly contributed from f electrons, whose bottom is located at $\mathbf{k} = (0, 0)$ start to emerge at the Fermi level (see Fig. 2(b)).

In the paramagnetic phase for $\varepsilon_f > \varepsilon_f^c$, $D(\mu)$'s have larger values than those in the AF phase, as shown in Fig. 3(b). The increase in the DOS toward ε_f^c in the paramagnetic phase is naturally understood since as ε_f decreases, $\bar{n}_f$ increases to approach 1, i.e., the Kondo state, giving rise to the reduction of T_K, i.e., enhancement of $D(\mu)$. In $CeRhIn_5$, the dHvA signal of the β_2 blanch has not been detected for $P > P_c$, probably because its effective mass is too large, close to $100m_0$.[9] This is also consistent with our result. For $\varepsilon_f > \varepsilon_f^c$, $D(\mu)$ decreases as h increases. This is also consistent with the field-dependence of m^* of the β_2 blanch in $CeCoIn_5$,[29] which is expected to correspond to the paramagnetic state of $CeRhIn_5$ for $P > P_c$.[23,30]

The increase in $D(\mu)$ toward ε_f^c, shown in Fig. 3(b), suggests that total DOS at the 3D Fermi surface of $CeRhIn_5$ gives rise to the measured peak structure of the A coefficient at $P = P_c$.[11] Our results clearly show that the "small" Fermi surface can be observed by dHvA measurement even without switching off the c-f hybridization, which reminds us of the elucidation of metamagnetism in $CeRu_2Si_2$.[31–33]

Recently, a possibility that the AF and paramagnetic transition is continuous under pressure has been reported by the In-NQR measurement at $H = 0$.[34] To clarify the detailed nature of the phase competition at the magnetic field smaller than the upper critical field, ~ 10 T, existence of the superconductivity should be taken into account, which is out of scope of the present study.

In summary, we have shown that the drastic change of Fermi surface with huge mass enhancement as well as the transport anomalies in $CeRhIn_5$ under pressure are naturally explained from the viewpoint of the interplay of the AF order and Ce-valence fluctuations.

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