SANS investigation of the heavy-fermion compound $CeRu_2Si_2$

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The theoretical studies [1 - 3] have shown that the orbital part of the magnetic scattering amplitude contains the term, which is singular at $q \to 0$ and gives rise the small-angle neutron scattering on the conduction electrons in metals:

$$F_{sing} = -i \cdot r \frac{\sigma [q \times p]}{q^2} \quad , \qquad (1)$$

where $r = |\gamma| e^2/mc^2 = 5.4 \cdot 10^{-13}$ cm and $\gamma = -1.91$ is the neutron g-factor; $\boldsymbol{q}$ is the momentum transfer and $\boldsymbol{p}$ is the electron momentum. It was also shown [1 – 3] that in metals the scattering cross section is proportional to $(m/M)^2$, where m is the effective mass of the electrons (carriers) and M is the mass of the neutron. For ordinary metals this factor is of order 10^{-5} - 10^{-6} and the neutron-electron scattering is negligibly small. However for some heavy-fermion substances $m \sim 100 m_e$ [4] and $(m/M)^2 \sim 10^{-2}$. In such cases the neutron-carrier scattering could be observed if one takes into account that the static cross section $d\Sigma(\vartheta)/d\Omega$ is proportional to ϑ^{-1} for $2E\vartheta >> T$ and $T/(\vartheta^2 E)$ for $T >> 2E\vartheta$, where $\vartheta << 1$ is the scattering angle and E is the neutron energy. The crossover from one regime to another is observed at $q_c = k \cdot \sin(T/2E)$.

In this work [5], small-angle neutron scattering experiments were carried out with $CeRu_2Si_2$ single crystal in order to directly observe SANS on heavy fermion quasiparticles and to analyze the magnetic field effect on this scattering. The system $CeRu_2Si_2$ is the archetypal heavy fermion compound with temperature Kondo $T_K \approx$ 25 K, which has no additional complexity such as superconductivity, magnetic phase transitions, etc. in the low temperature range. Moreover, it is well studied by different methods [6 -10].

The SANS experiment was performed at the SANS-1 scattering facility (reactor FRG1, GKSS, Geesthacht, Germany), which operates in near point geometry using neutrons with the wavelengths $\lambda \geq 4.5$ Å ($\Delta\lambda/\lambda = 0.1$). In the present experiment the wavelengths $\lambda_1 = 8.1$ and $\lambda_2 = 10.5$ Å were used. The range of momentum transfer $0.6 \cdot 10^{-3} < q < 2 \cdot 10^{-1}$ Å^{-1} was obtained using four sample-to-detector distances (0.7 – 9.7 m). The scattered neutrons were detected by a 2D position sensitive detector. The measurements were carried out in the range of the magnetic fields $0 \leq H \leq 2.5$ T at the temperatures $T = 0.85 \div 1.2$ K and 290 K.

In the course of SANS experiment we found, firstly, the additional small-angle scattering at $q \leq 0.04$ Å which may be attributed to the contribution of the neutron-carrier scattering to the orbital part of the magnetic scattering amplitude in this heavy-fermion system, as predicted theoretically in [3]. Secondly, it was found that the applied magnetic field results in both the increase of the observed scattering and its anisotropy with respect to the field direction. Moreover, measurements in the magnetic field reveal additional scattering for $q >$ 0.04 Å^{-1}, which is interpreted as neutron magnetic scattering by spin-density fluctuations with a correlation radius $R_c \approx 30$ A.

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