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**Scalar order: possible scenario for the low-field phase of $PrFe_4P_{12}$**

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The nature of the order parameter in $PrFe_4P_{12}$ skutterudite is now a longstanding problem and still mysterious. It seems that an antiferro-quadrupolar order of $\Gamma_3$ quadrupoles can explain most of the experimental results. However, the absence of induced perpendicular dipoles in the ordered phase for field directions (111) and (110) indicated by recent NMR results [1], or the isotropy of the magnetic susceptibility independent of the field direction are difficult to be interpreted with static quadrupoles.

We discuss the properties of a scalar-type order in general concentrating on behavior in external magnetic field, and point out that this scenario can be relevant to the low-field phase of $PrFe_4P_{12}$. With a scalar-type order parameter we can explain the isotropy of the magnetic susceptibility, and the fact that the induced staggered dipoles are anisotropic but always parallel to the field direction. Furthermore, the field angle dependence of the transition temperature obtained experimentally [2] can be reproduced well (see Figure 1).

We discuss also the $^{31}$P NMR spectra measured in $PrFe_4P_{12}$ [1]. We show that the main properties of the measured spectra can be explained consistently with the scalar-type order. We found that the induced octupoles play an indispensable role in the magnetic field dependences below and above the phase transition. The appearance of both the field induced dipoles and octupoles is a peculiar feature of the $T_h$ symmetry realized in the skutterudite systems.

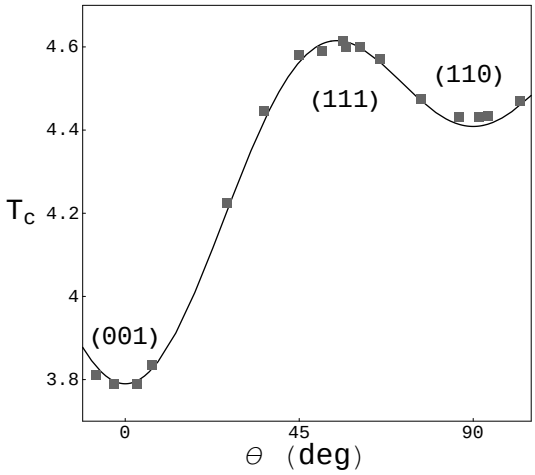


Figure 1: Transition temperature in non-zero magnetic field as a function of field angle. The boxes represent the measured result at $H = 2.7$T [2].

**References**

[1] J. Kikuchi et al., Physica B **359-361** (2005) 877.
[2] T. Sakakibara et al., to be published.