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TWO-DIMENSIONAL MAGNETIC STRUCTURES AND THE MULTI-STEP METAMAGNETIC PHASES IN $TbRu_2Si_2$

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The rare-earth compound $TbRu_2Si_2$ crystallizes in the $ThCr_2Si_2$-type structure (space group: *I*4/*mmm*), with the Tb ions, which are carrying the magnetic moment, arranged in the tetragonal body centred lattice. The magnetic behaviour is characterized by successive temperature induced transitions at T_N = 57 K, T_t = 5 K and T_t' = 4.2 K, and a multi-step metamagnetic transition (probably six steps up to a fully induced ferromagnetic phase) at low temperatures.[1] Figure 1 shows the field-temperature (*H*, *T*) magnetic phase diagram for $TbRu_2Si_2$, which is slightly modified when compared to the original one.[1] From single crystal neutron diffraction studies we have found that the high and intermediate temperature phases (phase I and phase II) at zero-field are, respectively, a one-dimensional spin arrangement with frustrated (2 0 0)/(1 0 0) Tb planes and a two-dimensional one with frustrated Tb sites[3] embedded in regular arrangements of antiferromagnetically coupled ferromagnetic (2 0 0)/(1 0 0) planes. The low temperature phase (phase III) is still unsolved.

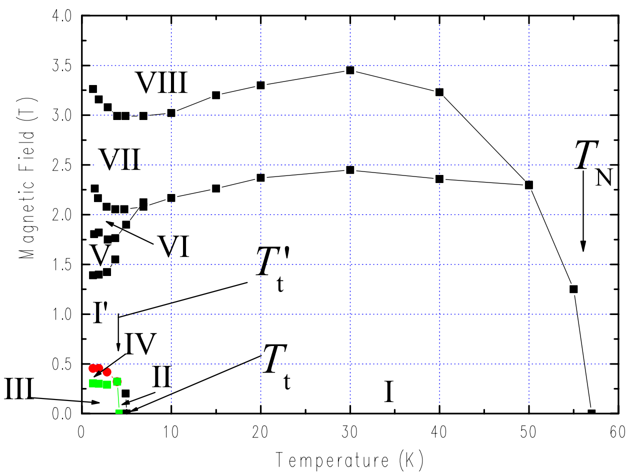

Fig. 1. Magnetic field versus temperature (H, T) Phase diagram for $TbRu_2Si_2$.

In the present note we report the results of pulsed and reactor-based neutron diffraction investigations of $TbRu_2Si_2$ revealing not only magnetic modulations of three ordered phases at zero-field but also those of the field-induced phases (phase IV to VIII) at 1.6 K. All the diffraction measurements were performed on the same $TbRu_2Si_2$ single crystal with the ***a**b**** reciprocal plane in the scattering plane. The reactor-based data were collected using the TAS3 neutron spectrometer at the Risø National Laboratory, Denmark. The pulsed neutron data were collected by use of the FOX diffractometer at the Neutron Scattering Facilities of the High Energy Accelerator Research Organization (KENS), Japan. The magnetic field was applied along the easy *c*-axis, i.e. the Bragg reflections, were collected only for (*h k* 0)-type reflections.

At zero-field we have modelled the magnetic order of phase I with a one-dimensional pattern which contains two frustrated (2 0 0)/(1 0 0) planes. The magnetic unit cell is $13a\times a\times c$, where *a* and *c* are the lattice constants of the original chemical cell and the order may be described by a propagation vector $\boldsymbol{Q}$ = (3/13 0 0). For phase II, the modelled magnetic order is two-dimensional ($13a\times 13a\times c$) and consists of a regular sequence of two antiferromagnetic/frustrated and 24 ferromagnetic (2 0 0)/(1 0 0) planes [3]. The low temperature phase III indicates also a two-dimensional arrangement with a smaller magnetic cell ($13a\times 4a\times c$) containing no frustrated Tb sites but two pure antiferromagnetic and 24 ferromagnetic (2 0 0)/(1 0 0) planes.

When an external magnetic field is applied at 1.6 K along the easy *c*-axis the predominant changes in the model magnetic order occur in the two antiferromagnetic/frustrated (2 0 0)/(1 0 0) planes. Phase IV appears at the first step in the magnetisation. This phase is also considered to be two-dimensional and is only slightly different from that of the zero-field phase II. The antiferromagnetic/frustrated Tb sites disappear and is replaced by one ferrimagnetic (2 0 0)/(1 0 0) plane in the $13a\times 13a\times c$ magnetic unit cell. In contrast, the following phase I' is again one-dimensional with a magnetic unit cell of $13a\times a\times c$ and contains 26 ferromagnetic (2 0 0)/(1 0 0) planes of Tb spins parallel or anti-parallel to the *c*-axis. Phase V is again two-dimensional ($13a\times 13a\times c$) and only slightly different from phase IV with one (2 0 0)/(1 0 0) ferromagnetic plane. The same is the case for phase VI but it contains two (2 0 0)/(1 0 0) ferrimagnetic planes. Also phase VII is two-dimensional, with regions of spins anti-parallel to the field direction regularly distributed in the sea of spins parallel to the field direction. Finally the spin structure becomes fully ferromagnetic. Each model phase results in a jump in the magnetization. The values of these jumps are in fair agreement with the observed value.

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