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LETTER TO THE EDITOR

Anisotropic spin-wave dispersion in $FeGe_2$

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Abstract. The first measurements have been made of the spin-wave dispersion in the tetragonal intermetallic compound $FeGe_2$ by inelastic neutron scattering. The experiments were performed at temperatures T between 4.2 K and 300 K in the collinear antiferromagnetic phase ($T < 263$ K) and in the incommensurate phase ($263 < T < 280$ K). There is no energy gap at zero wavevector. Along the a axis the spin-wave dispersion curve rises to a maximum frequency of 6.4 THz at the zone boundary. Along the c axis the frequency rises more rapidly with wavevector and reaches 11 THz approximately a sixth of the way to the Brillouin zone boundary. Measurements in the incommensurate phase indicate that the spin waves are overdamped along the a axis.

The antiferromagnetism in $FeGe_2$ has been studied extensively. The crystal structure of $FeGe_2$ is tetragonal, C16, with four iron atoms and eight germanium atoms in the unit cell. Layers of iron atoms alternate with layers of germanium atoms, and the magnetic structure in the low-temperature commensurate phase corresponds to each iron plane forming a face-centred square lattice with spins antiparallel at the centres and corners. It was first thought that the spins in alternate iron planes were not collinear [1], thus forming four distinct sublattices. Later neutron diffraction studies [2, 3] showed that, in fact, there are two sublattices and that the spins are collinear. This structure corresponds to ferromagnetically aligned chains along the c axis with antiferromagnet coupling between chains. Analysis of the effect of a magnetic field on the phase diagram [4] shows that a two-sublattice model is appropriate if the applied magnetic field is much smaller than the exchange field.

The most important result of the present work is the anisotropy between the relatively high-velocity spin wave showing no dispersion along the c axis and the lower-velocity spin wave with strong dispersion along the a axis. This may be understood in principle from the fact that the distance between adjacent iron atoms in the c-axis chains of parallel spins is 2.5 Å, similar to the interatomic distance in pure iron, 2.6 Å, and considerably smaller than the distance between the antiferromagnetic iron atoms in the a–a plane, 4.2 Å.

The neutron inelastic scattering experiments were carried out with the N5 triple-axis crystal spectrometer at the NRU reactor, Chalk River. The (113) planes of a silicon single crystal were used as monochromator and the (111) planes of silicon as analyser. Experiments were carried out at fixed scattering frequencies of 3.2, 4.0, 6.88 and 10 THz, depending on the frequency range of the excitations. The sample was mounted for scattering in the a–c plane, so as to be able to study excitations propagating along both the a and c axes. Experiments were carried out in a cryostat at temperatures of 4.2, 90, 130, 250, 275 and 300 K.

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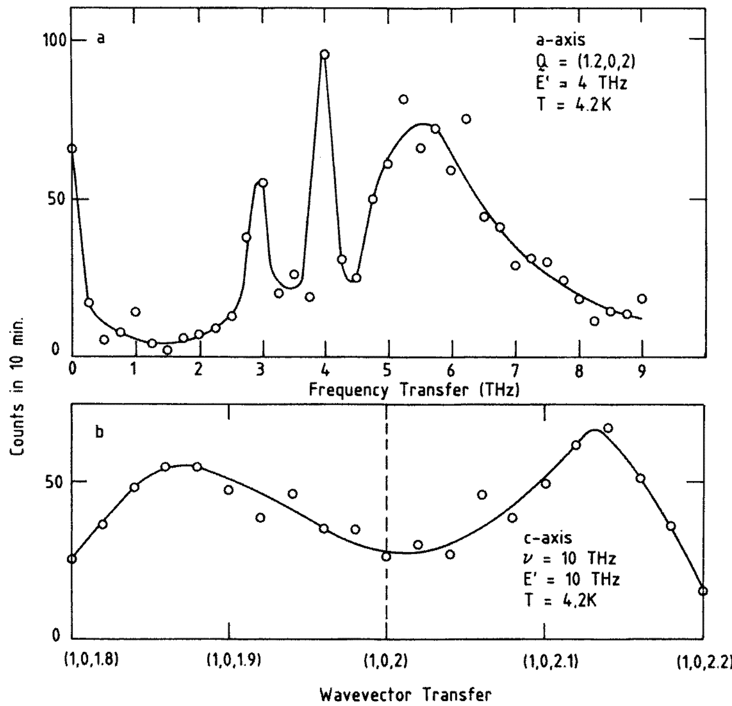

Figure 1. (*a*) A constant-$\boldsymbol{Q}$ scan in $FeGe_2$ at 4.2 K along the a axis, showing two sharp phonon peaks at 2.9 and 4.0 THz and a broad spin wave peak at 5.5 THz. The curve through the experimental points is a guide to the eye. (*b*) A constant-ν scan in $FeGe_2$ at 4.2 K along the c axis showing the magnon scattering at 0.13 $(2\pi/c)$ on both sides of the magnetic reciprocal lattice point (102).

Most measurements were made in the magnetic Brillouin zone centred on (102), a magnetic reciprocal lattice point at the boundary of the phonon Brillouin zone. A constant-$\boldsymbol{Q}$ scan at (1.2, 0, 2) and a constant-ν scan at frequency $\nu = 10$ THz at 4.2 K, in the a and c directions respectively, are shown in figure 1. The constant-$\boldsymbol{Q}$ scans show sharp phonon excitations at 2.9 and 4.0 THz and a much broader magnetic excitation at 5.5 THz. The character of the phonons were established by measurements at (1.2, 0, 4), where the magnetic peak diminished due to the magnetic form-factor, and also by measurements at 300 K, above the Néel temperature, $T_N = 293$ K. The magnon peak is much wider than the phonon peaks, suggesting that it is composed of several closely spaced unresolved peaks, or else that there is substantial intrinsic damping of the magnon.

The magnon and phonon dispersion curves for $FeGe_2$ at 4.2 K are shown in figure 2. The spin waves are clearly anisotropic. Along the c axis the frequency rises linearly and rapidly with wavevector, reaching 11 THz at less than a sixth of the way to the Brillouin zone boundary. The spin-wave velocity along the c axis is 5.9 ± 0.4 THz Å. Along the a axis the spin-wave frequency rises more slowly. The corresponding spin-wave velocity is 3.7 ± 0.4 THz Å. These spin-wave velocities are an order of magnitude smaller than those obtained, for example, in FCC manganese alloys [5]. There is no evidence for a finite spin-wave frequency at zero wavevector. The magnetic excitations in the vicinity of and just below the phonons were studied with constant-ν scans. These were made at 130 K,

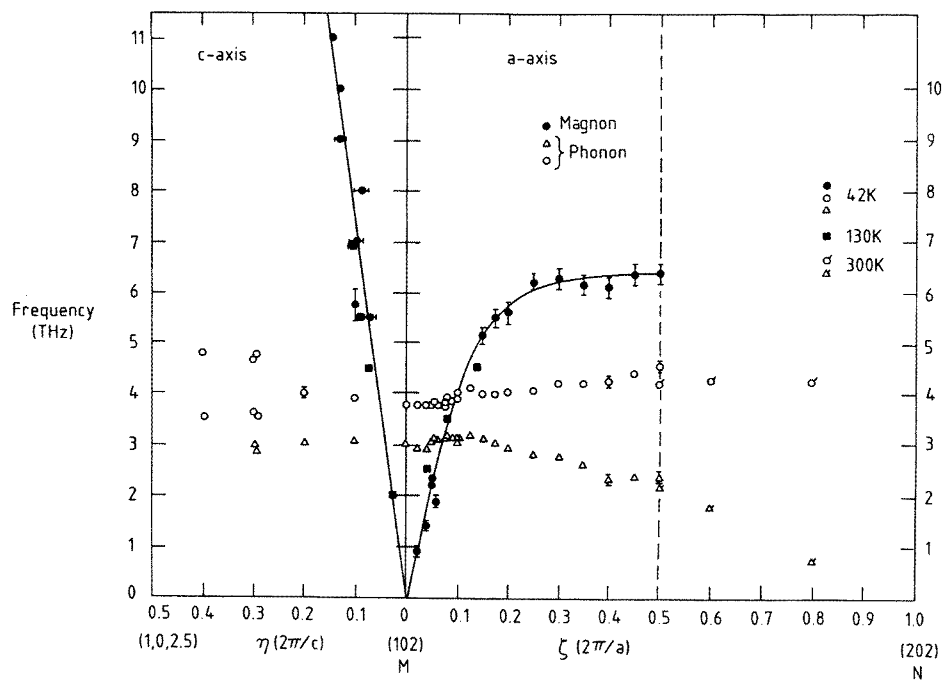

Figure 2. Frequency versus wavevector dispersion curves for $FeGe_2$ at 4.2 K along the *a* and *c* axes. The magnons are indicated by filled circles (4.2 K) and squares (130 K) and the phonons by open circles and triangles. The phonon frequencies in the Brillouin zone around the nuclear lattice point (202) were measured at 300 K and are denoted by tick marks on the symbols.

where the effects of softening are small, as discussed below.

There is little change in the spin-wave response between 4.2 K and 130 K. For example, the *a*-axis spin wave at wavevector (1.2, 0, 2), figure 1(*a*), falls at most by 0.3 THz in frequency, with no change of form or intensity. However, by 250 K, where FeGe is still in the commensurate phase, a well defined peak at a frequency higher than that of the phonons is no longer visible, and intensity builds up in the frequency region 0–2 THz. At 275 K, in the incommensurate phase (the commensurate–incommensurate phase transition occurs at $T_k = 263$ K), the low-frequency response further intensifies. Consistent with the behaviour in constant-$\boldsymbol{Q}$ scans, a constant-ν scan at 3.5 THz along the *a* axis shows two well-resolved peaks at 130 K, but only a single broad distribution centred on (102) at 275 K.

The behaviour along the *c* axis is subtly different. There is no change in the constant-$\boldsymbol{Q}$ scan at (1, 0, 1.9) between 4.2 and 130 K. At 250 K, only a shoulder is visible above the phonons, and only a tail at 275 K. However, in behaviour reminiscent of that of nickel [6], constant-ν scans along the *c* axis give two quite well defined peaks even at 275 K.

The subtle differences in the *a*- and *c*-axis behaviour suggests qualitatively that the generalized susceptibility falls off more slowly with wavevector along the *a* axis, where the inverse correlation length κ_a is large, than along the *c* axis where κ_c is small. This anisotropy is consistent with a picture of $FeGe_2$ where there is strong ferromagnetic exchange coupling within chains of spins parallel to the *c* axis, and weaker antiferromagnetic coupling between the chains in the *a*–*a* plane.

Work is in progress at the Rutherford–Appleton Laboratory (Dr C Adams' group) to explore the continuation of the *c*-axis branch of the spin-wave dispersion to much higher energies by the use of spallation neutrons.

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