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MAGNETOACOUSTIC INTERFEROMETRY OF METASTABLE STATES IN Dy₃Al₅O₁₂

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Abstract. We describe the construction and operation of an acoustic interferometer of exceptional sensitivity which we use to probe metastable phenomena that occur between the two time reversed antiferromagnetic states in Dy₃Al₅O₁₂, in the vicinity of the phase transition to the paramagnetic state.

The acoustic analogue of the Michelson interferometer provides a very sensitive method for measuring variations in the acoustic path length in a crystal [1]. Development of this technique has allowed measurement of changes in path length of about 1 part in 10⁹, enabling studies of magnetoelastic effects in the metamagnet Dysprosium Aluminium Garnet (DAG), for which unusual terms in the magnetoelastic energy allow striking variations in the sound velocity as a function of magnetic field.

The signal generator produces a monochromatic rf signal at a precise, stable frequency at about 1 260 MHz. Pulses of about 100 nS duration are sent to a thin film zinc oxide transducer, which is grown directly onto the sample under investigation. The transducer assembly has also been described elsewhere [2]. Improvement in the methods of deposition have made possible transducers with a very low insertion loss, comparable for both transverse and longitudinal bulk wave modes. Hence, a single transducer can be employed to investigate all the possible modes of acoustic propagation. Returning echoes from the transducer are, after conditioning, mixed with a suitably attenuated reference signal, which is derived from the same source, and sent to a gated integrator.

Variations of the amplitude of the returning echo can produce spurious results. This is a particular problem in the transverse echo in DAG, whose attenuation not only varies markedly with field, but is also different for each of the antiferromagnetic (AF) states. The signal is therefore amplified, and passed through a limiter, to remove any signal strength variation prior to mixing.

As the acoustic path length changes, echoes will change phase with respect to the reference carrier, and will interfere with it correspondingly. The exact relation between the final intensity and phase is complicated, but if the unmixed echo intensity is constant, the change in output of the power detector is the same for a given shift in frequency at fixed path length, as for the corresponding shift in acoustic path length at fixed frequency. Hence, measurements of the path length change can be made by measuring changes in frequency. As a first approximation, we neglect the small [3] contribution due to magnetostriction, and obtain the change in acoustic velocity in the sample of interest.

Figure 1 shows the change in the time of flight as a function of field below Tₐ for the longitudinal mode in a [001] direction plotted for sweeps for both "positive" to "negative" field and "negative" to "positive" field. The traces are slightly different, due to the sweep speed effects, but the equilibrium position for the two curves is the same.

![Fig. 1. - Change in effective path length Δτ/τ as a function of magnetic field for longitudinal acoustic waves at 1.4 K.](http://dx.doi.org/10.1051/jphyscol:19888921)

However, for a transverse mode, there is a vast difference between the two equilibrium curves as shown in figure 2. While the phase shift in the AF and mixed state is almost totally antisymmetric with respect to field, it is accurately symmetric in the higher field paramagnetic (PM) state.

This effect can be understood by examining the magnetoelastic energy. It is found [3] that DAG has some unusual terms in the magnetoelastic energy, linear in the AF order parameter, and linear in the magnetic field, giving the velocity of the transverse acoustic modes propagating in the [001] direction a contribution which is linear in the AF order parameter. This term will contribute in opposite directions in each of the two
time reversed AF states (A⁺ and A⁻) possible in the material below \( T_N = 2.5 \) K. In a magnetic field nearly parallel to [001], the energy degeneracy of these two states is lifted slightly, and one of the two AF states is favoured. As the magnetic field is reduced through the phase boundary, only the stable AF state is nucleated. For negative field, we denote this state as A⁻. This has a particular variation of acoustic path length with field, which corresponds to the "increasing" field trace. On reaching the positive field phase boundary, the system goes PM again. On sweeping field down again, the system nucleates in the other AF state (A⁺). Hence, the negative-going sweep reveals the variation of acoustic path length for the A⁺ state.

If one misaligns the field by a small amount (one degree is sufficient) from the [001] direction, the metastable states, corresponding to the upper lobes in figure 2, relax to the time-reversed stable state, but only at fields close to the phase boundary. The transformation can be arrested at any stage by reducing the field, thus stabilizing an arbitrary A⁺–A⁻ mixture. These effects are shown in figure 3. As the field is reduced further towards the other phase boundary, the mixture again relaxes, back to the original state, which is then the stable state.

The rate of relaxation is very sensitive to the exact field and misalignment involved. Figure 4 shows relaxations from metastable to stable states for various fields at a fixed misalignment angle (~1.4°) from [001]. The curves can be accurately scaled onto each other, with a scaling factor which is initially linear in field. Also, the traces obey a \((\text{time})^3\) law in the region which is clear of the relaxation start (and hence any complicating nucleation and transient magnetocaloric effects), and not too far into the transition (where growth will be complicated by competition within the growing stable phase for the now "rare" metastable phase). A \(t^3\) law is consistent with a simple linear growth of domains of the stable phase. Further details of this work will be published elsewhere.

![Fig. 2. Change in effective path length Δτ/τ as a function of magnetic field for transverse acoustic waves at 1.4 K.](image2)

![Fig. 3. Change in effective path length Δτ/τ as a function of magnetic field for the transverse mode in various mixtures of the two antiferromagnetic states, at 1.4 K.](image3)

![Fig. 4. Nature of the relaxation from the metastable to the stable antiferromagnetic state at 1.4 K, for a 1° field misalignment from [001], and a selection of field intensities, 0.59 T ≤ B ≤ 0.62 T. State = 1 refers to purely metastable, and State = 0 to the stable state.](image4)

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