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**Magnetocalorics –
Part 2: Measurement of magnetocaloric properties; Text in English**

Magnetokalorik–

Teil 2: Messung magnetokalorischer Eigenschaften; Text Englisch

Magnétocaloriques –

Partie 2: Mesure de propriétés magnétocaloriques; Texte en anglais

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Foreword

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Introduction

In the magnetocaloric community, different measurement protocols are used for the measurement methods to determine the parameters for the isothermal entropy change Δs_T and the adiabatic temperature change ΔT_{ad} , which limits the comparability of the results. In the case of Δs_T , there are also different ways of representing this quantity regarding its unit per mass or volume. This leads to discrepancies if the condition of the used sample and its density are not exactly known. For this reason, the standardization of the sample and measurement parameters as well as the nomenclature of the determined size and the use of the units are of decisive importance for finding a simple, unified language.

Standardization can thus ensure that no arbitrary measurement parameters are used that result in illusory results, but rather unified standards that lead to comparable values. This is an important factor for the transfer of the material parameters in application-oriented prototypes, because the technology is currently in a phase in which the cooperation between academic and industrial research is becoming increasingly important.

1 Scope

This document provides guidelines for the appropriate characterization measurements of magnetocaloric materials. It is aimed at researchers, manufacturers, and users to ease the communication of results regarding the development of new materials and the quality assessment of commercial and scientific samples. For second-order transitions, the measurement procedures can be formulated clear and unified, whereas for materials with a first-order phase transition, several aspects concerning the sample to be characterized have to be considered.

Therefore, this document provides guidelines for what conditions shall be ensured to measure meaningful values of ΔS_T and ΔT_{ad} . Since this can depend on the measurement device that is being used, boundaries are set, which need to be fulfilled and recommendations are offered how the suitability of measurement conditions can be validated. This will ensure that new actors in this field have a guideline to contribute with reasonable results and that producers have a standardized procedure to refer to when selling their products. Establishing these standards, combined with the unified terminology (see DIN SPEC 91373), and have them accepted and applied by all actors in this field are the first steps to set a common ground for the emerging magnetocaloric technology to grow into the market.

2 Normative references

The following documents are referred to in the text in such a way that some or all of their content constitutes requirements of this document. For dated references, only the edition cited applies. For undated references, the latest edition of the referenced document (including any amendments) applies.

DIN SPEC 91373, *Magnetocalorics — Terminology*

3 Terms and definitions

For the purposes of this document, the terms and definitions given in DIN SPEC 91373 and the following apply.

DIN and DKE maintain terminological databases for use in standardization at the following addresses:

- DIN-TERMinologieportal: available at <https://www.din.de/go/din-term/>
- DKE IEV: available at <http://www.dke.de/DKE IEV>

4 Sample properties

It is important to note for all the following described methods that the application of an externally applied magnetic field differs from the effective internal magnetic field present. Magnetic materials create a demagnetizing field, which locally lowers the externally applied magnetic field H_a acting on the material. This self-demagnetizing field depends on the magnetization M of the sample and its geometry. For a rotational ellipsoid with uniform magnetization the demagnetizing field is constant throughout the shape and can be expressed using a simple factor N . The internal magnetic field H_i at all points throughout the sample is then given by:

$$H_i = H_a - NM \quad (1)$$

For a very long and thin sample, N is close to 0 along the long axis, while for a very thin plate-like sample it is close to 1 perpendicular to the surface. For non-ellipsoid shapes, N and H_i vary throughout the shape and are non-trivial to determine analytically, but in most cases they can be numerically approximated to a simple factor within an accuracy acceptable for magnetocaloric parameters.

In order to avoid this calculation, a sample for a magnetic measurement shall be at least 5 times longer than it is wide and the magnetic field shall be applied along its long axis. This limits the effects of the self-demagnetizing field and the factor N can be neglected. For other cases, the demagnetization has to be accounted for and H_i needs to be calculated properly from the sample geometry.

The mass of the sample shall be measured with a sufficiently high precision in order to determine the specific entropy change of the material.

The transition temperature of first-order materials depends very strongly on their composition. Hence, the chemical homogeneity shall be ensured very carefully.

5 Isothermal entropy change $\Delta s (M, T, H)$

5.1 Introduction

This sub-clause deals with the determination of the entropy change of magnetocaloric materials from magnetization measurements. The entropy change can also be determined by other means, such as caloric measurements, which will be discussed in clause 6.

Key to the correct determination of the isothermal entropy change is the measurement of the magnetization at different applied magnetic fields and different temperatures. This data can then be used to calculate the relevant magnetocaloric properties. This method provides an essential characterization technique to assess the potential of magnetocaloric materials for cooling purposes since the entropy change gives an estimate for the amount of heat energy that the material can absorb/release for a given external magnetic field change.

5.2 Brief summary of procedure

In general, a complete dataset of the magnetization at different temperatures and magnetic fields is necessary to determine the entropy change. Its calculation is based on the Maxwell relation for magnetic materials:

$$\left(\frac{\partial M}{\partial T}\right)_H = \left(\frac{\partial S}{\partial H}\right)_T \quad (2)$$

These relations can be used in the case of second-order phase transitions. For ideal first-order materials these derivatives do not always exist, because the thermodynamic potentials involved are not continuous. For these the simplified version of the Clausius-Clapeyron equation can be used:

$$\left(\frac{\Delta M}{\Delta T}\right)_H = \left(\frac{\Delta S}{\Delta H}\right)_T \quad (3)$$

5.3 Devices

In order to determine the isothermal entropy change of a magnetocaloric material, the (mass or volume) magnetization of the sample, which can be calculated from its magnetic moment and the mass/volume, needs to be measured in dependence of external magnetic field and the sample temperature. Therefore, the measurement equipment for determination of the isothermal entropy change for magnetocaloric materials consists typically of a device ensemble that is able to produce and measure a magnetic field, sweep and measure the temperature of the sample chamber and measure the magnetization of the sample. The most common method is the vibrating sample magnetometry (VSM). Here, the sample is attached to the sample holder, which is being vibrated with a certain frequency. The changing of the magnetic flux emanating from the sample movement with respect to the coil positions induces a signal in the pickup coils, from which the magnetic moment of the sample can be calculated.