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A Manual for

Condensed Matter Physics

for beginners

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Chapter 1

Magnetism

> Science is rooted in conversations.
>
> —— Werner Heisenberg (1901 - 1976)

1.1 Magnetic Properties

1.1.1 Magnetic susceptibility

Definition

Magnetic susceptibility (denoted χ) is a dimensionless proportionality constant that indicates the degree of magnetization of a material in response to an applied magnetic field. It indicates whether a material is attracted into or repelled out of a magnetic field. Quantitative measures of the magnetic susceptibility also provide insights into the structure of materials, providing insight into bonding and energy levels.[1]

The definition of magnetic susceptibility (volume susceptibility) is as followed

$$\mathbf{M} = \chi \mathbf{H} \tag{1.1}$$

where $\mathbf{M}$ is the magnetization of the material (the magnetic dipole moment per unit volume), and $\mathbf{H}$ is the magnetic field strength.

A material can be **paramagnetic** ($\chi > 0$) or **diamagnetic** ($\chi < 0$) depending on whether the magnetic field in it is strengthened or weakened by the induced magnetization.

While volume susceptibility is a dimensionless constant, mass susceptibility and molar susceptibility are **not**. They are defined as

$$\chi_{\text{mass}} = \frac{\chi}{\rho} \tag{1.2}$$

and

$$\chi_{\text{mol}} = M\chi_{\text{mass}} = \frac{M\chi}{\rho} \tag{1.3}$$

where ρ is the density in $\mathrm{kg/m^3}$ and M is molar mass in kg/mol.

[1] See wikipedia page: Magnetic susceptibility.

Different Unit Systems

Noted that in SI units, the magnetic induction $\mathbf{B}$ is related to $\mathbf{H}$ by the relationship

$$\mathbf{B} = \mu_0(\mathbf{H} + \mathbf{M}) = \mu_0(1 + \chi)\mathbf{H} = \mu\mathbf{H} \tag{1.4}$$

where μ_0 is the vacuum permeability, and $(1+\chi)$ is the relative permeability of the material. Thus the volume magnetic susceptibility χ and the magnetic permeability μ are related by the following formula

$$\mu = \mu_0 (1 + \chi) \, . \tag{1.5}$$

However in Gaussian units (or cgs emu, which is the same for magnetic properties), the magnetic induction $\mathbf{B}$ is related to $\mathbf{H}$ by the relationship

$$\mathbf{B} = \mathbf{H} + 4\pi\mathbf{M} = (1 + 4\pi\chi)\mathbf{H}. \tag{1.6}$$

For a conversion between SI units and Gaussian units, please refer to this table.

Susceptibility Tensor

The magnetic susceptibility of most crystals is not a scalar quantity. Magnetic response $\mathbf{M}$ is dependent upon the orientation of the sample and can occur in directions other than that of the applied field $\mathbf{H}$. In these cases, volume susceptibility is defined as a tensor

$$M_i = H_j \chi_{ij} \tag{1.7}$$

where i and j refer to the directions (e.g., x and y in Cartesian coordinates) of the applied field and magnetization, respectively.

Differential Susceptibility

In ferromagnetic crystals, the relationship between $\mathbf{M}$ and $\mathbf{H}$ is not linear. To accommodate this, a more general definition of differential susceptibility is used

$$\chi_{ij} = \frac{\partial M_i}{\partial H_j} \tag{1.8}$$

where χ_{ij} is a tensor derived from partial derivatives of components of $\mathbf{M}$ with respect to components of $\mathbf{H}$.

1.1.2 Neél Temperature

1.1.3 Curie Temperature

1.2 Ferromagnetism

1.3 Antiferromagnetism

1.4 Ising Model

More text.

Chapter 2

Miscellany

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