4. Magnetic Properties of Crystals

As noted above, crystallography widely uses the ideas of symmetry as a basis for crystal investigations. In this chapter we shall consider the magnetic phenomena precisely from this standpoint. Our attention will be focused on magnetic symmetry and the application of the symmetry principles in explaining the anisotropy of the physical properties and describing the structures of magnetic crystals. In discussing the anisotropy of the physical properties of ferromagnetics, we use the tensor method, which is traditional for crystallography. The previous courses of crystallography practically ignored the anisotropy of ferromagnetic crystals.

Restricting ourselves to the specific “crystallographic” aspects and to the minimum necessary information from the theory of magnetism, we naturally cannot dwell on some other important problems relating to the magnetic properties of crystals. This chapter completely omits the resonance phenomena, problems associated with the behavior of magnetically ordered crystals in alternating fields, and optical and other “nonmagnetic” properties. Nor does it fully cover questions concerning the wide use of magnetic materials in modern technology, although they are partially discussed in passing. All this information can be found in the specialized textbooks and monographs on magnetism which are listed in the Bibliography.

4.1 Disordered Magnetics

4.1.1 Basic Relations Characterizing the Behavior of a Substance in a Magnetic Field

By the magnetic properties of a substance is meant the ability of bodies to interact with a magnetic field. It is well known that any moving electrically charged body or particle produces a magnetic field of its own and thus interacts with the external magnetic field. It follows that magnetism is a universal property of any substance, because matter is inconceivable without moving charged particles.

A substance placed in a magnetic field \( H \) is magnetized. It acquires a resultant magnetic moment consisting of the elementary magnetic moments of...
the separate particles. A characteristic, or a measure, of the magnetized state of a substance is *magnetization* $I$, or the magnetic moment of a unit volume. In moderate fields, there exists the following simple relationship between $I$ and field $H$:

$$I = \chi H,$$

(4.1)

where $\chi$ is the *volume magnetic susceptibility* of the substance. In addition to volume susceptibility $\chi$, the *molar susceptibility* ($\chi_{\text{mol}}$) and the *specific susceptibility* ($\chi_{\text{spec}}$) are sometimes used. Their relationship is given by expressions $\chi_{\text{spec}} = \chi/\varrho$, $\chi_{\text{mol}} = \chi M/\varrho$, where $\varrho$ and $M$ are the density and the molecular weight. Accordingly, *molar* and *specific magnetization* are distinguished. The latter is usually denoted by $\sigma$.

Inside the magnetized substance an intrinsic field $4\pi I$ is induced; therefore, another vector, the *magnetic induction*, is introduced in addition to vectors $I$ and $H$:

$$B = H + 4\pi I.$$  

(4.2)

Substituting (4.1) into (4.2), we obtain

$$B = H(1 + 4\pi \chi) = \mu H.$$  

(4.3)

The quantity $\mu = 1 + 4\pi \chi$ is called the magnetic permeability of the substance.

If a body of an open shape is subjected to magnetization, "magnetic charges" arise on the surface of the body in the direction of the external field and induce an additional magnetic field $H_d$ directed inside the body oppositely to the external field. Field $H_d$, which is called the *demagnetizing field*, is, to a first approximation, proportional to the magnetization:

$$H_d = -N I,$$

(4.4)

where $N$ is the so-called *demagnetizing factor*, which depends on the shape of the body. Taking into account the demagnetizing field, the total true field inside the body, which actually causes magnetization $I$, will be equal to

$$H = H_e + H_d = H_e - NI,$$

(4.5)

where $H_e$ stands for the external magnetic field. Allowance for the demagnetizing field is essential only for strong magnetic substances (for instance, ferromagnetics), for which the value of $I$ is comparable with the external field. Note that field $H_d$ is homogeneous only for elliptical bodies.

Substituting (4.5) into (4.1), we get

$$I = \chi H = \frac{\chi}{1 + \chi N} H_e = \chi_0 H_e,$$

(4.6)