

## 20 The hysteresis curve

*Subject:*

When the subject “Magnetic fields in matter” is discussed, dia-, para- and ferromagnetism is introduced. For ferromagnetic substances the hysteresis effect is characteristic. Among other things, the concept of remanent magnetism is introduced.

*Deficiencies:*

Although magnetic forces are more pronounced and more easily accessible by simple experiments than electrostatic forces, physics students as well as physics teachers, are less versed with magnetostatic phenomena than with electrostatics. One of the reasons for this deficiency is the tradition of explaining ferromagnetism by introducing the hysteresis effect. As a result, the learner gets the impression that the behavior of magnets is essentially determined by the complicated hysteresis curve.

Actually, the hysteresis curve can be considered a manifestation of the imperfection of a magnetic material. We consider two extreme cases of magnetic materials: the perfect soft magnetic and the perfect hard magnetic substances. A perfect soft magnet does not allow for a magnetic field in its interior. Inside of such a material  $\mathbf{H} = \mathbf{0}$ . Thus, a soft magnetic material is analogous to an electric conductor with respect to an electric field: An electric conductor does not tolerate an electric field in its interior, we have  $\mathbf{E} = \mathbf{0}$ . A perfect hard magnetic material is characterized by the property, that its magnetization cannot be changed by means of a magnetic field. Thus,  $\mathbf{M} = \text{const}$ . It is exactly this property which is wanted. A “permanent” magnet that changes its magnetization under the influence of a magnetic field is not a permanent magnet. Actually, both types of perfect materials can nowadays be realized to within a good approximation. The hysteresis curve expresses that by means of an external field which is sufficiently strong, one can destroy the permanent magnetization of a hard magnet, or one can reach saturation of a soft magnetic material. Under normal conditions, however, these phenomena will not be significant. Thus, beginning the introduction of the magnetism of materials with the hysteresis curve means to begin with imperfect materials. It is similar to beginning the discussion of elastic springs by overstretching the spring. Also in this case a hysteresis effect is observed.

*Origin:*

Only some decades ago it was appropriate to introduce ferromagnetism via the hysteresis curve. The materials which could be realized at that time were still far away from being perfect hard or soft magnetic materials. It was easy to change the magnetization of a permanent magnet. When the geometry of a magnet was unsuitable, the magnetization succumbed the magnet's own field. Under these circumstances it was appropriate to speak about a remaining or remanent magnetization.

*Disposal:*

We begin the discussion of magnetism in matter with the introduction of the perfect hard magnetic and the perfect soft magnetic material. For a hard magnetic material we have  $\mathbf{M} = \text{const}$ , and for a soft magnetic material we have  $\mathbf{H} = \mathbf{0}$ . The magnetization of a permanent magnet is not disdainfully called remanent magnetization. The hysteresis curve, as well as dia- and paramagnetism are introduced in the solid state physics course at the university.

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