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Physics behind the magnetic hysteresis loop—a survey of misconceptions in magnetism literature

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Abstract

An extensive survey of misinterpretations and misconceptions concerning presentation of the hysteresis loop for ferromagnetic materials occurring in undergraduate textbooks has recently been carried out. As a follow-up, this article provides similar examples, now drawn from recent magnetism literature. The distinction between the two notions of '*coercivity*' referred to the B vs. H curve and the M vs. H curve, which turn out to be often confused in textbooks is elucidated. Various misinterpretations and conceptual problems revealed by our survey of recent magnetism-related scientific journals are summarized. In order to counteract the misinterpretations in question, some real examples of hysteresis loops showing the correct characteristics have also been identified in this search. Various ways of presenting units for the same physical quantity, i.e. the SI or cgs units as well as both units mixed, have been revealed in the regular articles. This is a worrying factor, which calls for a concerted action at the level of the whole magnetism community. A number of intricacies and fundamental conceptual problems in magnetism encountered in a recent review are dealt with in a separate note.

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Keywords: Ferromagnetism; Paramagnetism; Hysteresis loop; Coercivity; Coercive force

1. Introduction

The rationale for this study has originally come from our teaching solid state physics (SSP)/condensed matter physics (CMP) course, which includes five lectures on magnetism. Some inconsistencies concerning the presentation of the hysteresis loop for ferromagnetic materials found in textbooks currently used for our course have prompted us to carry out an extensive survey of textbooks. The survey has covered the areas of (a) solid state physics/condensed matter physics, (b) general physics, (c) materials science and magnetism/electromagnetism, as well as relevant encyclopedias and physics dictionaries. We have examined in total about 300 textbooks. The survey has given us more than we bargained for, namely, it has revealed various other substantial misconceptions than those originally identified in the SSP/CMP area. For the benefit of physics teachers (as well as researchers) and students the results of the textbook survey and the pedagogical aspects are

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presented in a Research Report [1]. A free copy of the Report may be obtained from the authors upon request; it may also be accessed via our Departmental homepage: http://www.ap.cityu.edu.hk or downloaded directly from: ftp://www.ap.cityu.edu.hk/Research-report/.

In order to provide the counterexamples for the misconceptions identified in the textbooks, we have also surveyed a sample of recent scientific journals searching for real examples of the magnetic hysteresis loops, beyond the schematic diagrams found in most textbooks. It appears that the data on the magnetic materials discovered in the last two decades have barely filtered into the textbooks. Moreover, to our surprise, apart from several intricacies concerning the presentation of the hysteresis loops, a number of misconceptions concerning basic aspects of magnetism have also been identified in some research papers. During our work on the extended survey we have realized that the results warrant a separate article in a scientific journal devoted to magnetism studies. Hence in this paper, which is a follow-up to [1], we focus on the research aspects and provide a review of recent literature data on soft and hard magnetic materials.

In Section 2, for the sake of completeness, we define the two notions of coercivity to clarify their distinction and categorize briefly the various misconceptions and misinterpretations revealed by our textbooks survey [1]. Similar analysis of the intricacies concerning the magnetic hysteresis graphs identified in recent magnetism-related research literature is carried out in Section 3. Pertinent examples of the values of important technological parameters and references to the hysteresis loop data for 'real' soft and hard magnetic materials are also provided. A number of general conceptual problems concerning magnetism that have crept into the review [2] are discussed in a separate note.

2. Two notions of coercivity and misconceptions/misinterpretations in textbooks

The relationships between the magnetic induction (or the magnetic field intensity) inside the sample, $\boldsymbol{B}$, the applied magnetic field, $\boldsymbol{H}$, and the magnetization induced inside the sample by $\boldsymbol{H}$, are defined as (see, e.g. [3–4]):

$$\boldsymbol{B} = \boldsymbol{H} + 4\pi\boldsymbol{M} \ \text{(cgs)}, \quad \boldsymbol{B} = \mu_0(\boldsymbol{H} + \boldsymbol{M}) \ \text{(SI)}, \quad (1)$$

whereas the total magnetization $\boldsymbol{M}$, due to any individual (e.g. electronic or atomic) magnetic moments $\boldsymbol{m}$ existing in the sample, is defined as the magnetic moment per unit volume V:

$$\boldsymbol{M} = \frac{1}{V}\sum_{v} \boldsymbol{m}. \quad (2)$$

The variation of B vs. H and M vs. H is non-linear due to the characteristic of domains existing in ferromagnetic materials. Full discussion of the formation of the hysteresis loop and the properties of domains may be found in, e.g. [3–5]. Both curves B vs. H and M vs. H have similar general characteristics, except for one crucial point. After the saturation point is reached, the M vs. H curve becomes a straight line with exactly zero slope, whereas the slope of the B vs. H curve reflects the constant magnetic susceptibility. In other words, the B vs. H curve does not saturate by approaching a limiting value as in the case of the M vs. H curve.

The roots of the misconceptions and misinterpretations concerning the hysteresis loop for ferromagnets appearing in textbooks have been discussed in Ref. [1]. Major problems turn out to stem from the confusion between the properties of the two types of hysteresis loops: B vs. H and M vs. H, as well as the properties of the soft and hard magnetic materials. Some authors define either the *related coercivity* [4] or the *intrinsic coercivity* [5,6] H_{ci} as the reverse field required to reduce the magnetization M from the remnant magnetization M_r again to zero, whereas reserve the symbol H_c and the name *coercivity* (coercive force) to denote the reverse field required to reduce the magnetic induction in the sample B to zero [4]. Most often, however, an identical symbol, most commonly H_c, is used for both quantities [1]. The distinction between the two meanings of coercivity is illustrated schematically in Fig. 1(a) M vs. H and (b) B vs. H, together with the other pertinent quantities indicated. As amply evidenced in Ref. [1], the two meanings of '*coercivity*' are not

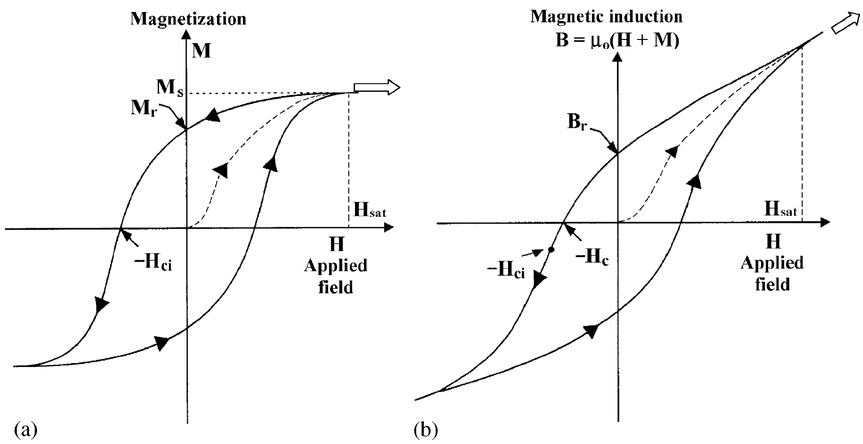

Fig. 1. Hysteresis curves for a ferromagnetic material: (a) M vs. H: M_r is the remnant magnetization at $H=0$; H_{ci} is the intrinsic coercivity, i.e. the reverse field that reduces M to zero; M_s is the saturation magnetization; (b) B vs. H: B_r is the remnant induction (or 'remanence') at $H=0$; H_c is the coercivity, i.e. the reverse field required to reduce B to zero (adapted from Ref. [5]).

equivalent, although their values may be very close for some materials. Below, we categorize briefly the various misconceptions and misinterpretations revealed by our textbooks survey [1].

2.1. *Misinterpretation of the coercivity H_c on the B vs. H curve as the point at which M=0*

The textbook examples of such misinterpretations, i.e. inappropriate identification of H_c as the point on the B vs. H curve (see, Fig. 1), where magnetization is zero, have been discussed in detail in Ref. [1]. Here, we briefly outline the major reasons and consequences of such misinterpretations. One reason comes from the identical name '*coercivity*' and notation '$-H_c$' often used for both curves: M vs. H and B vs. H. The two types of hysteresis loop seldom appear together in the same book, usually either the M vs. H curve or the B vs. H curve is used. As a result, without clearly distinguishing the terminology (see, Fig. 1): H_c and H_{ci}, confusion may arise. A serious consequence is that magnetization is taken as zero at H_c on the B vs. H curve, i.e. the erroneous (*in general*) identification: $H_c \equiv H_{ci}$ occurs. Such problems also arise when the authors attempt to present a more advanced topic in a simpler way in which an approximation was made without clearly clarifying the distinction between H_c and H_{ci} for the hard and soft magnetic materials. Since the value of M is much larger than that of H for soft magnetic materials, the approximation $B \approx \mu_0 M$ in Eq. (1) holds [3] and so $H_c \approx H_{ci}$. However, the equivalence between the two quantities does not hold for hard magnetic materials. As the magnet technology progressed, the distinction between H_c and H_{ci} has become quite pronounced. In Table 1, we have compiled the values of H_{ci}, H_c, and B_r for several commercially available permanent magnetic materials revealed by our recent Internet search. As a consequence of $H_{ci} \neq H_c$, the magnetization does not reach zero at the point $-H_c$ on the B vs. H curve but at a larger value of H_{ci} indicated schematically in Fig. 1(b). The data [7–9] collected in Table 1 indicate that although H_c and H_{ci} are of the same order of magnitude, in a number of cases H_{ci} is substantially larger than H_c. Hence, it is necessary to distinguish between H_c and H_{ci}.

2.2. *Misconceptions concerning the meaning of the saturation induction B_{sat}*

The term of '*saturation induction*' is also prone to confusion, whereby the magnetic induction inside a ferromagnetic material is ascribed the same saturation behavior as the magnetization, i.e. $B = B_s = \text{const}$ as $M = M_s = \text{const}$. However, no '*saturation*' of the induction can occur, even with

Table 1
Data for selected permanent magnet samples obtained from Internet search—see the websites listed in: (a) Ref. [7], (b1, b2) Ref. [8], and (c) Ref. [9]

Samples H_{ci} (kOe)	Intrinsic coercivity H_{ci} (kOe)	Coercive force H_c (kOe)	Remanence B_r (kGs)
Sintered magnets: GS-1[a]	17.0	11.6	12.2
Sintered magnets: GS-2[a]	12.0	9.0	11.5
Sintered magnets: GS-3[a]	14.0	10.4	10.5
Bonded NDFEB magnets: GPM-4[b1]	8.0–10.0	3.0–3.5	3.5–4.5
Bonded NDFEB magnets: GPM-6[b1]	8.0–10.0	4.0–4.5	5.0–6.0
Bonded NDFEB magnets: GPM-8[b1]	8.0–11.0	4.5–5.5	6.0–6.7
Bonded NDFEB magnets: GPM-8H[b1]	13.0–17.0	5.0–5.8	5.6–6.5
Rubber magnet: YZT04[b2]	1.9–2.0	1.2–1.4	1.5–1.7
Rubber magnet: YZT07[b2]	1.9–2.0	1.7–1.9	1.9–2.0
NdFeB 36SH[c]	23	11.7	12.2

further increase of H. The neglect of the contribution of H to B in Eq. (1) is seldom clearly clarified in text or graphs leading to misinterpretation of the physical meaning of the '*saturation induction*'. Examples of such misinterpretations in text or misrepresentations of the B vs. H curve in the surveyed textbooks are also outlined in Ref. [1].

2.3. Misconceptions concerning the actual inclination of the B vs. H and/or M vs. H curve after saturation

Concerning the actual inclination of both B vs. H and M vs. H curves after full saturation of magnetization, misinterpretations may arise if the apparent inclinations of the B vs. H type hysteresis loops are ascribed to zero, as in the case of the inclination of the M vs. H curves. In order to find out what the actual appearance of the B vs. H curve looks like, we have simulated the inclination for various scales used for the x- and y-axis of the hysteresis loop. The results are presented in Fig. 3 of Ref. [1].

2.4. Misconceptions concerning the dependence of the shape of the hysteresis loop on the direction of the applied field

The shape of the hysteresis loop for magnetically soft materials are usually presented in a simplified way, especially in the less advanced textbooks. The aspect of anisotropy of magnetization of magnetic materials was usually seldom mentioned in textbooks. Usually, the shape of hysteresis loop appeared in textbooks either like loop (A) or loop (B) in Fig. 4(a) of Ref. [1]. In some surveyed textbooks, the dependence of the shape of hysteresis loop on the direction of the applied field in the sample with respect to the '*easy*' direction or '*hard*' direction was well clarified. However, one crucial point was omitted, see, e.g. Jakubovics [10]. The two different curves, i.e. along the easy and hard direction, did not show the same level of saturation magnetization. This is contrary to the physical requirement that the total saturation exhibited by a material is the same in any direction. This is confirmed by our survey of research papers [11–30] as indicated by hash (#) in Table 2—for detailed discussion see Section 3.

2.5. Misconceptions arising from the hysteresis loops for both soft and hard materials presented in the same figure or using the same scale

The comparison of hysteresis loops for both soft and hard magnetic materials plotted schematically in the same diagram appear in several textbooks [1]. Generally, such comparison can give a clear picture to the readers. However, an opposite effect may be achieved, i.e. it may give a wrong impression to the reader, if the scales used for

Table 2
Summary data for real materials extracted from the B vs. H or M vs. H hysteresis graphs appearing in recent research literature. The comments denoted by asterisks (*), double asterisks (**), hashes (#) and double hashes (##) are explained in detail below. The reduced magnetization M/M_s is dimensionless as indicated by (N/A)

X-axis		Y-axis		Type of materials	Comments	Refs.
Name and/or symbol	Units	Name and/or symbol	Units			
(a) *Journal of Magnetism and Magnetic Materials*						
Magnetic field B_{ap}	T	Magnetization M	Am^2/kg	Fe, Ni, Co nanowires	#; Various shapes in one graph	Paulus et al. [11]
H	Gauss*	Magnetization M	emu/g	$(Fe_{0.26}Ni_{0.74})_{50}B_{50}$	#; '*Apparent*' inclination in different graphs	Zysler et al. [12]
Applied field H_a	Oe	Reduced magnetization M/M_s	N/A	Not mention	#; '*Apparent*' inclination for several hysteresis loop in one graph	El-Hilo et al. [13]
H	kOe	M/M_s	N/A	Fe/CaF_2 multilayers	#; Inclination tends to zero slope for several hysteresis loop	Mosca et al. [14]
H	Oe	M	emu/cm^3	Ni_xPt_{1-x} alloys	#; Various shapes in different graphs	Vasumathi et al. [15]
H	Oe	M	emu	HCP-CoCrPt–SiO_2	##; Hard direction: '*apparent*' inclination; easy direction: zero slope inclination	Xu et al. [16]
H	Oe	M/M_s	N/A	Fe nanowire	#; Hard direction: '*apparent*' inclination; easy direction: zero slope inclination	Yang et al. [17]
Applied field H	kOe	Magnetization M	kGs	$Sm_{19}Fe_{67}C_{14}$ alloys	##; Inclination tends to zero slope	Geng et al. [18]
Magnetic field	Oe	M/M_s	N/A	1. $Co_{75}Si_{15}B_{10}$ monolayers 2. $Fe_{80}B_{20}$	1. #; '*Apparent*' inclination 2. #; Inclination tends to zero slope	Mandal et al. [19]
Applied field H	G*	Magnetization M	emu	Nickel nanoparticle films	Various shapes and asymmetric hysteresis loop in one graph	Zhang et al. [20]
Magnetic field H	kOe	Magnetization M	cm^3G/mol	$[Mn(R)_4TPP][TCNE]$ $(R = OC_{12}H_{25}, F, CN)$	#; Various shapes in one graph	Balanda et al. [21]

Table 2 (*continued*)

X-axis		Y-axis		Type of materials	Comments	Refs.
Name and/or symbol	Units	Name and/or symbol	Units			
(b) *Physica B*						
$\mu_0 H$	T	Magnetization J	T	$Nd_2Fe_{14}B$-films	#; Hard direction: '*apparent*' inclination; easy direction: zero slope inclination	Melsheimer [22]
H	Oe	Magnetization	N/A	$Fe_{0.7}Si_{0.3}$	Inclination tends to zero slope	Álvarez-Prado [23]
H	Oe	Magnetization M/M_s	N/A	Co/Ni multilayers; Co/Al oxide/ permalloy trilayers	#; Various shapes in the same graph	González [24]
Applied field H	Tesla	M	emu/g	$(La_{0.7-x}Bi_x)\ Ca_{0.3}MnO_3$ $(0.05 \leqslant x \leqslant 0.7)$	Various shapes in the same graph	Barandiaran [25]
H	Oe	Magnetization M/M_s	N/A	CoMnSiB	Inclination tends to zero slope	Vázquez [26] **
H	kA/m	Magnetization M/M_s	N/A	Co nanowires	#; Inclination tends to zero slope	Vázquez [26] **
H	Oe	$\mu_0 M$	T	FeSiBC	#; Inclination tends to zero slope	Vázquez [26] **
H_Φ/H_k ; Circular magnetic field H_Φ; circumferential anisotropy constant H_k	N/A	M_Φ/M_s	N/A	$(Fe_{0.06}Co_{0.94})_{72.5}Si_{12.5}B_{15}$	##; '*Apparent*' inclination as well as inclination tends to zero slope in the same graph.	Gómez-Polo [27]
H	Am^{-1}	M/M_s	N/A	Not mentioned	#; Various shapes in the same graph	Aranda [28]
B_{appl}	T	Magnetization M	Am^2/kg	Fe–Pt alloy	#; Inclination tends to zero slope	Thang et al. [29]
H	kOe	M	emu/mol	Gd_2CuO_4	Various shapes in the same graph	Martinho et al. [30]

*: Improper unit of Gauss (G) used for the magnetic field H.

**: Both SI and cgs units used in the same articles concerning different hysteresis loops

#: Correct contra examples of the misconceptions (D)—various hysteresis curves reached the same value of saturation magnetization M_s for the same magnetic material after fully internal saturation of magnetization.

##: Incorrect examples, i.e. of the misconceptions (D)—various hysteresis curves did not reach the same value of saturation magnetization M_s for the same magnetic material after fully internal saturation of magnetization.

the *x*-axis and *y*-axis for a given curve are not stated. The difference between H_c for soft and hard magnetic materials is very large. Usually, it ranges from several hundreds in the cgs units (or 3 orders of magnitude in the SI units) to 10,000 times or more in the cgs units (or 6 orders of magnitude in the SI units). However, any comparison for both soft and hard magnetic material plotted together in the same diagram (for references, see Ref. [1]) just indicates that H_c for hard magnetic materials is only, at best, several times larger than that for the soft materials.

2.6. Other problems concerning terminology

Various minor problems concerning confusing terminology have also been identified in our survey [1]. A wide variety of naming conventions and symbols used as well as improper usage of the terms like '*polarization*' to describe the properties of magnetization leads to confusion. Similar problems appear in some research articles as discussed below.

3. General intricacies concerning the magnetic hysteresis in recent research literature

In order to counterbalance the misinterpretations and confusion summarized briefly in Section 2 (for details, see Ref. [1]), it is illustrative to find examples of pertinent correct discussion of hysteresis loops in recent research literature. This may also help clarifying the misconceptions in textbooks. We have surveyed papers published in last three years in two key magnetism-related scientific journals, namely, *Journal of Magnetism and Magnetic Materials* and *Physica B*. The aim was to identify the examples of experimental hysteresis loops showing correct characteristics in order to provide counterexamples for the misinterpretations and confusion found in textbooks [1]. A number of pertinent examples of the B vs. H or M vs. H hysteresis graphs for real materials have been identified in recent research literature. However, in addition to the majority of appropriate examples, i.e. showing the hysteresis loops with the correct shape, our survey has also revealed several occurrences in the regular articles, to a lesser extent, of similar misconceptions as those found in the textbooks [1] and outlined in Section 2. In Table 2 we present the summary data extracted from the scientific journals. Table 2 serves also as an illustration of the current situation in magnetism literature regarding the names, symbols, and units used for major magnetic quantities. The sample, yet representative, data collected in Table 2 allow the following general observations.

We note that various names are being used for the quantities H, B, and M. It turns out that in spite of the existing uniform standard, i.e. the SI units, adhered to in the majority of recent textbooks [1], the researchers still very often use the cgs units (see Section 4). In Table 2 the inappropriate usage of the units is denoted by an asterisk '*', as e.g. 'Gauss' and 'G' for H—see, e.g. Zysler et al. [12] and Zhang et al. [20], respectively, whereas by the double asterisks '**' for both the SI and cgs units used in the same article containing different hysteresis loops—see, e.g. Vázquez [26]. Data concerning the respective hysteresis curves showing the same level of magnetization after full internal saturation for a given magnetic material are indicated by hash '#', whereas the cases where apparently this condition is not satisfied are denoted by the double hash '##'.

Concerning the misinterpretation of the coercivity H_c on the B vs. H curve as the point at which $M = 0$ (see Section 2.1), although H_c and H_{ci} were clearly distinguished on the graph in Ref. [2] reproduced in Fig. 2, the wording of the text in Ref. [2] indicates a confusion. The '*normal*' curve corresponds to the B vs. H curve as in Fig. 1(b), while the '*intrinsic*' curve corresponds to the M vs. H curve as in Fig. 1(a). However, there is an inconsistent description in text in [2], implying that H_c and H_{ci} are equivalent. For instance, in the review [2] the description of '*normal coercivity*' H_c refers to the point in which '*no net magnetization*' on the B vs. H curve appears, whereas '*intrinsic coercivity*' H_{ci} refers to the point in which '*the magnet is completely demagnetized*'. Actually, these two statements refer to different curves in Fig. 2, but they reflect the fact that magnetization $M = 0$ for both cases. It implies, incorrectly—as discussed

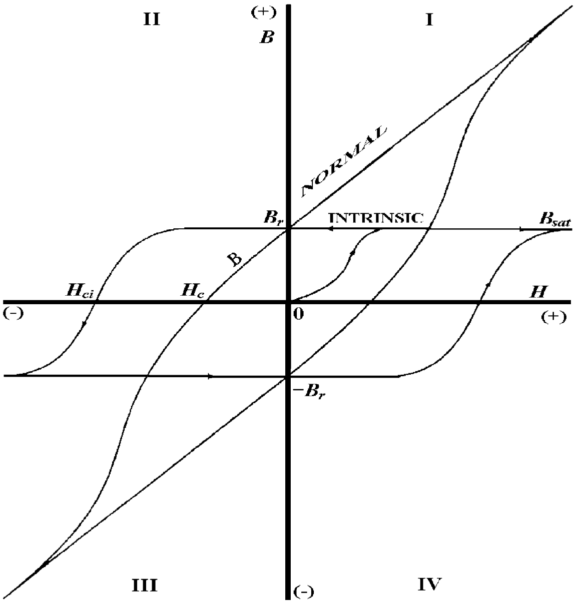

Fig. 2. Hysteresis loops for a ferromagnetic material. The term '*normal*' refers to the B vs. H curve like the one in Fig. 1(b), whereas the term '*intrinsic*' refers to the M vs. H curve like the one in Fig. 1(a). 'B_{sat}' here means saturation magnetization (adapted from Ref. [2]).

in full in Ref. [1], that both H_c and H_{ci} are equivalent.

Another problem leading to confusion in Ref. [2] is the poorly defined notation B_{sat} for the M vs. H curve as shown in Fig. 2. In fact, this confusion can be avoided if the symbol M_{sat} is used instead. In fact, as discussed above, saturation of induction cannot be achieved on the B vs. H curve. There exists only the '*saturation magnetization*' M_s for ferromagnetic materials. The '*magnetic induction*' B will still increase with H after M_s is reached, no matter how small the effect may be. Inappropriate usage of terminology as discussed in Section 2.5 is also noted. Coey [31] uses confusingly '*spontaneous polarization*' instead of '*spontaneous magnetization*' to illustrate the magnetic property. Another example is: *Engineers sometimes use the polarization J of a magnet instead of its magnetization M when looking at magnetization* [2]. Interestingly, both '*spontaneous polarization*' and '*spontaneous magnetization*' are mentioned in the same article dealing with magnetism [22]. Such improper terminology proliferates confusion by mixing up two distinct physical quantities.

Concerning the shape of hysteresis loop for the ferromagnetic materials, the anisotropy of magnetization is mainly responsible for the various shapes encountered. The shape depends also on the different physical conditions, e.g. temperature, the applied field direction with respect to the easy or hard direction, etc. These aspects are usually oversimplified in textbooks. Some real examples of the correct shape together with the corresponding comments are listed in Table 2. The comment '*apparent inclination*' in Table 2 refers to the shape of the M vs. H hysteresis curves showing an apparent inclination, just before reaching full saturation, which is beyond the range of H measured, and hence is not indicated on the graph. The curves showing nearly no inclination are indicated by the comment: '*inclination tends to zero slope*'. The comment '*various shapes*' indicates the cases where the inclination of hysteresis loops varies from an apparent inclination to the zero slope inclination either in the same graph or in different graphs. The real examples in Table 2 provide counterexamples for the misconceptions described in Sections 2.3 and 2.4 and strongly support our view that oversimplification has lead to the confusion in the textbooks discussed in Ref. [1]. They provide also experimental evidence that the schematic curves should reach the same level of magnetization after full internal saturation for a given magnetic material (see the cases '#' in Table 2). However, an inappropriate impression may be created by the graphs in the regular articles, see, e.g. [16,18,27], in which the hysteresis curves do not reach the same level of full saturation of the magnetization (see the cases '##' in Table 2). Because the total magnetization of the magnetic material does not depend on the physical condition, the shape of the hysteresis loop should reach the same level. Hence, the graphs in Ref. [16,18,27] should be reinterpreted.

It is worth mentioning that additional pertinent examples of experimental and simulated B vs. H and M vs. H curves can be found in the Proceedings of recent conferences: the Third International Symposium on Hysteresis and Micromagnetics Modeling [32] and the Fifth

Latin American Workshop on Magnetism, Magnetic Materials and their Applications [33]. For a deeper understanding of the physics underlying the magnetic hysteresis loops, the two recent theoretical papers may be consulted [34,35].

4. SI versus cgs unit systems

Concerning the various ways of presenting units (see Table 2), the dominant usage of the cgs units in the research papers surveyed by us is a factor that requires special attention of the magnetism community. For instance, Am^2/kg, emu/g, emu/cm^3, emu, kGs, cm^3G/mol, are being used for the units of magnetization, whereas T, Oe or kOe, G or Gauss, are being used for the applied field. This variety and non-uniformity regarding units in the research magnetism literature is in contrast with the situation in the high school and university education as reflected by the respective education textbooks, where the SI units are commonly enforced. Probably not only the forces of 'scientific' inertia but also the physical advantages of the old unit system may be responsible for the dominant usage of the cgs units in the regular research articles, instead of the SI units. However, the disparity between the '*official standards*' and the '*actual practice*' creates not only an inconvenience, but delays the uniform acceptance of the SI units. Additional problems concerning units as discussed above include, e.g. the units of 'Gauss' ('G') being misused for H (see the cases (*) in Table 2) and mixed usage of both the SI and cgs units (see the cases (**) in Table 2). The inconsistent usage of units depends, to a certain extent, on the authors' habits. However, in order to achieve uniform standards in all scientific literature, the gap between the researchers and the textbook authors must be narrowed. However, a dilemma arises: should the usage of the SI unit system in scientific journals be encouraged and possibly enforced or should we accept continuation of the usage of the cgs unit system? The educational and overall scientific considerations speak strongly in favor of the standard SI units.

5. Conclusions and summary

The possible root of the misinterpretations and confusions discussed in Ref. [1] and in this paper may be two-fold: (1) the usage in the literature of the same notation for two distinct physical quantities as well as (2) several notations being used for the same physical quantity. In the latter case confusion concerns mainly nomenclature and should be avoided. However, in the former case, the usage of the same name and/or symbol has led to the misinterpretation of the two distinct physical notions as being equivalent to each other. This case concerns the notion of '*coercivity*', which has been widely adopted in undergraduate textbooks for describing, confusingly, both the B vs. H and M vs. H curves. Proper distinction between the '*intrinsic coercivity*', $H_{ci,}$ and the '*coercivity*', H_c, to describe the M vs. H curve and the B vs. H curve, respectively, is necessary in order to avoid creating confusion. Unfortunately mixing up the two notions has been wide spread in advanced level textbooks resulting in several misinterpretations and confusions as reviewed by us in [1]. Concerning the magnetism-related scientific literature, similar problems appear in some research papers, to a lesser extent. However, other problems have also been revealed as discussed above.

We hope that the clarification of the inconsistencies in notations and misinterpretations existing in the literature dealt with in the present paper and the detailed research report [1] as well as the note [36] will filter into the textbooks and scientific journals. This would improve the quality of the textbooks and hence enhance the students' understanding of the subject as well as improve the standards of presentation of the data on the magnetic properties of materials in scientific literature. This is a worrying factor, which calls for a concerted action at the level of the whole magnetism community. Concerning the existing various ways of using the units, it is strongly recommended to unify the usage of the units in order to avoid further confusion. The pro and cons of the SI and cgs units should be reconsidered and a consistent approach should be uniformly adopted in the research papers. The current situation in this regard, as revealed by our survey, is rather worrying and calls for a concerted action at the level of the whole magnetism community. Especially, a stronger cooperation between the journal publishers and the authors in this regard is needed. The unification of units would bring benefits both to researchers and students in the magnetism area.

During the work on the unification process the specialized magnetism-related books, which have not been specifically dealt with in this paper, should be also reviewed. This is a formidable task in itself, since a number of advanced books in this category have been published, especially in the last decade. The author's (CZR) experience indicates that some of these books are not be free from other terminological problems, which require a separate consideration. Here we only point out, after an anonymous referee of this paper, that the discussion of the basic aspects of material magnetism and the historical account of the development of unit systems in magnetism is worth presenting for the benefit of the magnetism researchers. This is beyond the scope of the present paper. Following the suggestion of the referee, we refer the readers to the book by Panofsky and Phillips [37] for a comprehensive presentation of the units and dimensions in electromagnetic theory. We also note that there is some justified reluctance by the authors of advanced magnetism books to use the SI units in favor of the cgs emu units, see, e.g. Aharoni [38] and Hubert and Schäfer [39].

In summary, in this paper, taking as the starting point equation (1), we report on the existing situation in the research magnetism literature regarding misconceptions concerning the hysteresis loop. For a comprehensive treatment of various other related problems unraveled by the present study, especially the unit systems, a separate paper would be warranted. Each unit system has its advantages and disadvantages, but the major question is which of the two options is more beneficial to the community in the long terms: (a) existence of several unit systems or (b) a uniform unit system being internationally accepted. For the most recent guide for metric practice, see the note by Nelson [40] (and references therein). It is pertinent to quote from [40]: *"An important function of the SI is to discourage the proliferation of unnecessary units"*.

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