# Magnetostriction of transition-metal–metalloid glasses: Temperature dependence

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Linear, saturation magnetostrictions $\lambda_s$ of a variety of $(FeCoNi)_{80}B_{20}$ glasses have been studied as a function of temperature. Magnetostrictions over the range 4.2 K $\lesssim T \lesssim T_C$ for selected glasses, $Fe_{80}B_{20}$, $Co_{40}Ni_{40}B_{20}$, and $Ni_{50}Fe_{30}B_{20}$, are shown to follow reasonably well the theory of Callen and Callen for single-ion anisotropy of uniaxial-strain symmetry, i.e., $\lambda_s(T)/\lambda_s(0) = \hat{I}_{5/2}(X) \equiv I_{5/2}(X)/I_{1/2}(X)$ with $I_{3/2}(X) \equiv m(T)$, the reduced magnetization. The anomalous temperature dependence of the magnetostriction observed in the cobalt-rich $(FeCo)_{80}B_{20}$ glasses is attributed to the combination of a positive two-ion (anisotropic-exchange) term plus a stronger, negative, one-ion (crystal-field) term. A change of sign in $\lambda_s$ occurs along the Co-Ni side of the triangular Fe-Co-Ni$(B_{20})$ diagram due to a change in sign of the dominant single-ion mechanism. This sign change results from a change in the orbital character of the states at the Fermi energy as it passes from the top of the cobalt or nickel $3d^{\downarrow}$ band to the bottom of the iron $3d^{\downarrow}$ band.

## I. INTRODUCTION

Recent interest in metallic glasses[1] (noncrystalline metallic alloys) may be attributed both to their technological potential[2-4] and to the fact that they represent a novel isotropic medium in which to study a variety of physical phenomena. Of growing interest among the magnetic properties of transition-metal–metalloid (TM-M) glasses are their magnetic anisotropy[5-10] and magnetostriction.[2,11-14] Information on the *orbital character* of the magnetic electrons can be obtained from such measurements while saturation magnetic moments give information about the *number* of unpaired spins per atom. However, the weak magnetic anisotropy ($10^2$–$10^4$ erg/cm$^3$) of TM-M glasses is difficult to measure accurately. Consequently, numerous examples of conflicting, or at least inconsistent, studies of magnetic anisotropy in TM-M glasses[5-10] exist in the literature.

Magnetostrictions of metallic glasses are generally not much smaller than those of comparable crystalline alloys and thus provide a viable means of studying magnetic anisotropy. Magnetostriction is related to the strain derivative of the anisotropy energy.[15] The magnetic Hamiltonian with exchange and crystal-field terms, respectively,[16]

$$H = \vec{S}_i \cdot \overleftrightarrow{J}_{ij} \cdot \vec{S}_j + \vec{S}_i \cdot \overleftrightarrow{D} \cdot \vec{S}_i \qquad (1)$$

where $\vec{S}_i$ is the spin operator at site $i$, may therefore be generalized to include magnetoelastic effects by expanding $\overleftrightarrow{J}_{ij}$ and $\overleftrightarrow{D}$ to first order in the strain $\epsilon_\mu$:

$$H = \vec{S}_i \cdot \overleftrightarrow{J}^0_{ij} \cdot \vec{S}_j + \vec{S}_i \cdot \overleftrightarrow{D} \cdot \vec{S}_i + \epsilon_\mu \vec{S}_i \cdot \frac{\partial \overleftrightarrow{J}_{ij}}{\partial \epsilon_\mu} \cdot \vec{S}_j + \vec{S}_i \cdot \frac{\partial \overleftrightarrow{D}}{\partial \epsilon_\mu} \cdot \vec{S}_i \cdots . \qquad (2)$$

The equilibrium strain is obtained by adding to Eq. (2) the elastic energy $\frac{1}{2}C_\mu \epsilon_\mu^2$, treating the strain derivatives as perturbations, and minimizing the resulting free energy with respect to $\epsilon_\mu$. Magnetic anisotropy may arise from either of the resulting anisotropic terms $\langle S_i^z S_j^z \rangle$ and $\langle (S_i^z)^2 \rangle$ with appropriate two-ion or one-ion coefficients; magnetostriction may arise from either of the anisotropic terms with the appropriate strain-derivative coefficients.

Measurements of the temperature dependence of magnetostriction in $Fe_{80}B_{20}$ glass have, accordingly, provided the first clear indication of the nature of the anisotropic interaction responsible for magnetostriction (and presumably also for intrinsic magnetic anisotropy) in TM-M glasses.[13] In the present paper, these measurements are extended to cobalt- and nickel-containing metallic glasses,[17] and conclusions concerning the nature and origin of magnetostriction in TM alloys are drawn.

In Sec. II, some important experimental considerations are presented. Section III briefly summarizes the theoretical basis for interpreting the temperature-dependence results which are found in Sec. IV. Discussion and a summary of conclusions are found in Secs. V and VI, respectively.

Before an investigation of the temperature dependence of magnetostriction in metallic glasses can be pursued, however, it is important to note first the isotropic nature of magnetoelastic effects in metallic glasses. Secondly, it should be made clear that the low-field effects resulting from changes in domain patterns of unsaturated materials by stress-relief and field-annealing[18-20] below the crystallization temperature have no bearing on magnetic properties measured above saturation (e.g., $\lambda_s$). Thirdly, it should be remarked that the temperature dependences observed here are characteristic of the glassy state and in no way resemble the behavior of $\lambda_s(T)$ in the crystallized[21] samples of the same compositions.[22]

## II. EXPERIMENTAL

Essential details of the process of fabricating the metallic glass ribbons[23] and of making the magnetostriction measurements[12-14] have been presented elsewhere. For magnetostriction measurements, semiconductor strain gauges were used at room temperature and metal foil gauges and polyamide adhesive were used for the temperature-dependent studies. Sample temperature was measured with a Chromel-alumel thermocouple ($T \gtrsim 77$ K) and a cryogenic linear temperature sensor[24] ($4.2 \leq T \leq 80$ K) in intimate contact with the specimen. Magnetization measurements were performed with a commercial vibrating sample magnetometer. Curie temperatures were determined by the equation of state (Arrott) method.

## III. THEORETICAL BACKGROUND

The temperature dependence of magnetostriction can reveal information about the nature of the mechanisms causing the magnetoelastic effects as well as, by association [(Eq. (2)], those causing magnetic anisotropy. The basis for obtaining such information is the quantum-statistical-mechanical theory of Callen and Callen.[16,25,26]

This theory is derived from a Hamiltonian for localized-moment, crystalline, magnetic materials. However, in addition to describing well the magnetostriction and anisotropy in a variety of magnetic insulators,[16,27,28] it has proven to be applicable to crystalline rare-earth metals[17,26,29] and, to some extent, to the crystalline transition metal Ni.[16,30] The behavior of magnetostriction in crystalline iron[31] and cobalt[32] is complex and not well understood. More recently the theory of Callen and Callen has been shown to describe $\lambda(T)$ in the iron-rich glass $Fe_{80}B_{20}$.[13] The present results suggest that the theory is in fact generally applicable to transition metals, at least in the isotropic glassy state.

The theory describes the temperature dependence of magnetostrictive strains (and magnetic anisotropy) in terms of thermally averaged single-ion $\langle (S_i^z)^2 \rangle$ and two-ion, $\langle S_i^z S_j^z \rangle$ and $\langle \vec{S}_i \cdot \vec{S}_j \rangle$, spin-correlation functions. These three terms give rise, respectively, to (i) single-ion anistropy and single-ion anisotropic magnetoelastic effects, (ii) two-ion anisotropy (anisotropic exchange) and linear magnetostriction arising from such anisotropic, two-ion interactions and (iii) zeroth order (isotropic) terms in the magnetic energy and isotropic, volume magnetostriction and anomalous thermal expansion. The effects arising from isotropic exchange $\langle \vec{S}_i \cdot \vec{S}_j \rangle$ are generally larger than the anisotropic effects, however, they are not discussed further here.[26,33]

The anisotropic spin-correlation functions [(i) and (ii) above], show characteristic temperature dependences. Therefore, the temperature dependence of reduced magnetostriction should reveal the single-ion or two-ion nature of the anisotropic spin correlations. Further description of the detailed mechanism (e.g., spin-orbit, spin-other-orbit, or spin-spin interaction)[34] is not possible in metals by this method.

## IV. RESULTS

Room-temperature magnetostrictions have been reported for the two series of glasses $Fe_{80-x}T_xB_{20}$ ($T$ = Co, Ni).[12,14] These data are displayed here on a triangular diagram (Fig. 1) which includes new data on $(CoNi)_{80}B_{20}$ glasses and several pseudoternary $(FeCoNi)_{80}B_{20}$ glasses. One important feature of Fig. 1 is the line connecting compositions of zero magnetostriction.[35] This line is essentially temperature independent and will be discussed in more detail below.

In order to gain insight into the origin of magnetostriction in these materials, particularly with regard to sign changes in $\lambda_s$, it is desirable to study the temperature dependence of $\lambda_s$ in at least three compositions, rich in Fe, Co, and Ni, respectively. However, the Ni-rich glasses in the area roughly bounded by the dotted line in Fig. 1, are not presently fabricable by continuous, rapid-quench techniques. Also the Curie temperatures

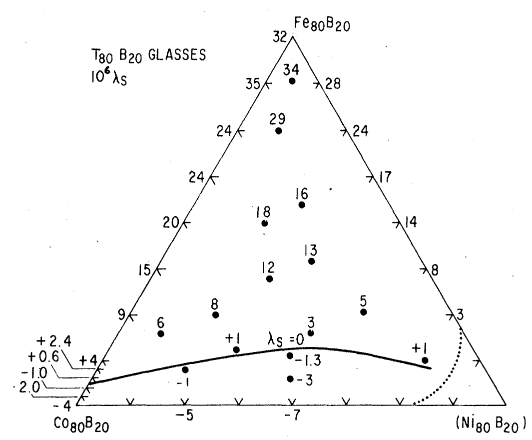


FIG. 1. Magnetostriction as a function of TM content for $(FeCoNi)_{80}B_{20}$ glasses. Solid line: $\lambda = 0$. Compositions to the Ni-rich side of dotted line are not currently fabricable.

TABLE I. Curie temperature $T_C$, crystallization $T_X$ and ambient magnetostriction of the metallic glasses chosen for comparison with theory.

| Glass composition | $T_C$ (K) | $T_X$ (K) | $10^6\lambda_s$(295 K) |
|---|---|---|---|
| $Fe_{80}B_{20}$ | 647 | 720 | +32 |
| $Ni_{50}Fe_{30}B_{20}$ | 575 | 685 | +8 |
| $Co_{40}Ni_{40}B_{20}$ | 610 | 615 | −7 |
| $Co_{70}Fe_{10}B_{20}$ | ~850 | ~675 | +4 |
| $Co_{74}Fe_6B_{20}$ | ~840 | ~650 | +0.6 |
| $Co_{80}B_{20}$ | ~830 | ~625 | −4 |

$T_C$ of cobalt-rich glasses generally exceed their crystallization temperatures $T_X$ to the extent that the magnetization and magnetostriction vary little from 4.2 K to $T_X$ (see Fig. 7 below). This renders a comparison with theory difficult. Attention was focused, therefore, on the three representative glasses $Fe_{80}B_{20}$, $Ni_{50}Fe_{30}B_{20}$, and $Co_{40}Ni_{40}B_{20}$. Their Curie and crystallization temperatures as well as $\lambda_s$ (295 K) are shown in Table I. In these glasses, $T_C$ is sufficiently less than $T_X$ that $\lambda(T)$ may be measured up to $T_C$ without danger of devitrification. The temperature dependence of $\lambda_s$ in cobalt-rich glasses is described separately.

Figures 2–4 show the temperature dependence of magnetostriction and magnetization for the three selected metallic glasses. The quantities displayed here, $\lambda(T$, 2 kOe) and $\sigma(T$, 8 kOe), do not vanish at $T = T_C$ because of the applied field.[36] Below $T/T_C \cong 0.8$ they are equivalent, within experimental error, to saturation values.

Figure 5 shows the reduced-temperature dependence of $\lambda_s(T)/\lambda_s(0)$ and $\sigma(T)/\sigma(0)$ for $Fe_{80}B_{20}$ glass only. The data points here are taken from the average line drawn through the data in Fig. 2. The inset shows that the magnetostriction varies as $[m(T)]^3$ up to $T/T_C \approx 0.6$. Figure 5 illustrates the intermediate step in preparing the data for comparison with the theory in which the temperature dependence of $\lambda_s(T)$ is expressed in terms of the parameter $\sigma(T)$.

Figure 6 plots the reduced magnetostrictions as functions of the reduced magnetizations for the three samples. Theoretical lines for single-ion anisotropy of uniaxial symmetry $\hat{I}_{5/2}(X)$, and cubic symmetry $\hat{I}_{9/2}(X)$ and for anisotropic two-ion exchange of uniaxial symmetry, $[m(T)]^2$, are shown

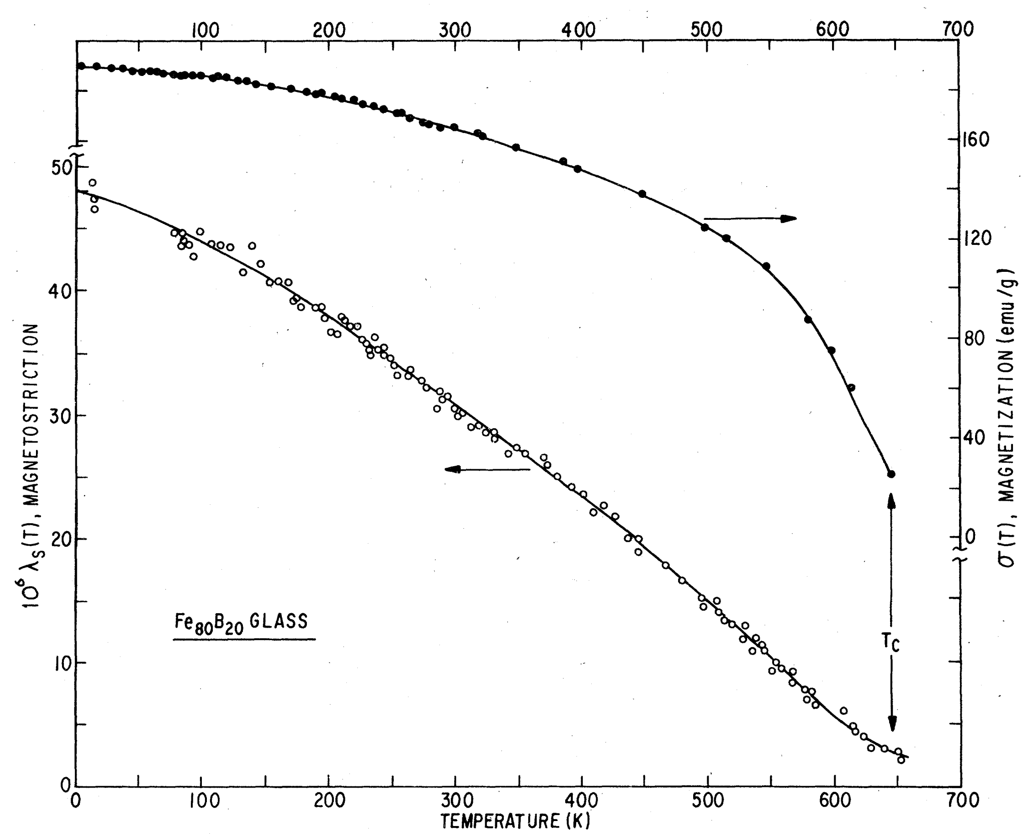


FIG. 2. Magnetostriction (left-hand scale) and magnetization in 8 kOe (right-hand scale) as a function of temperature in $Fe_{80}B_{20}$ glass.

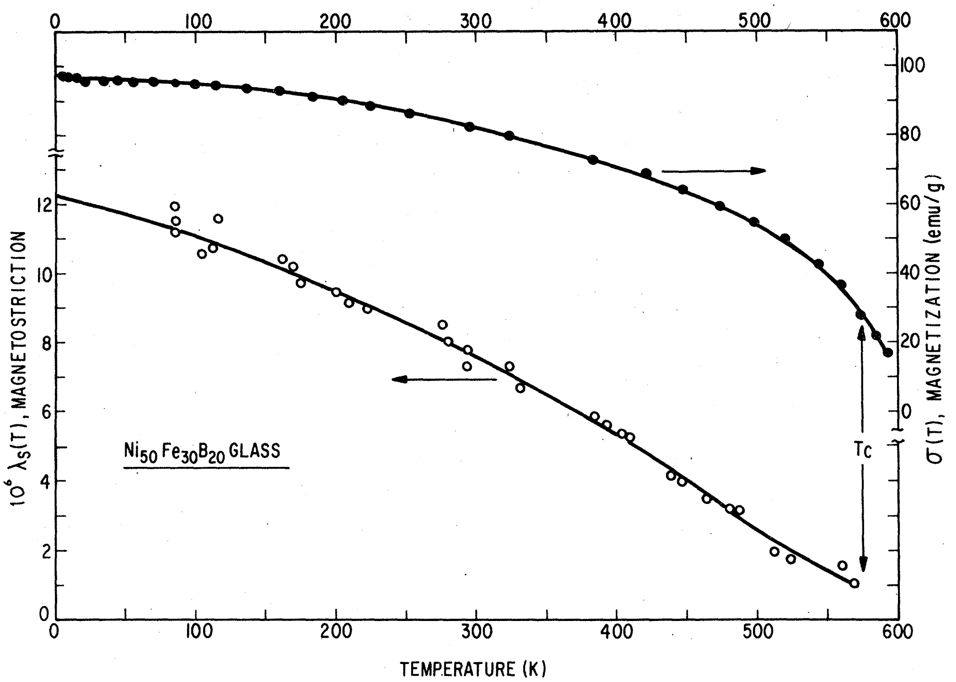


FIG. 3. Magnetostriction (left-hand scale) and magnetization in 8 kOe (right-hand scale) as a function of temperature in $Ni_{50}Fe_{30}B_{20}$ glass.

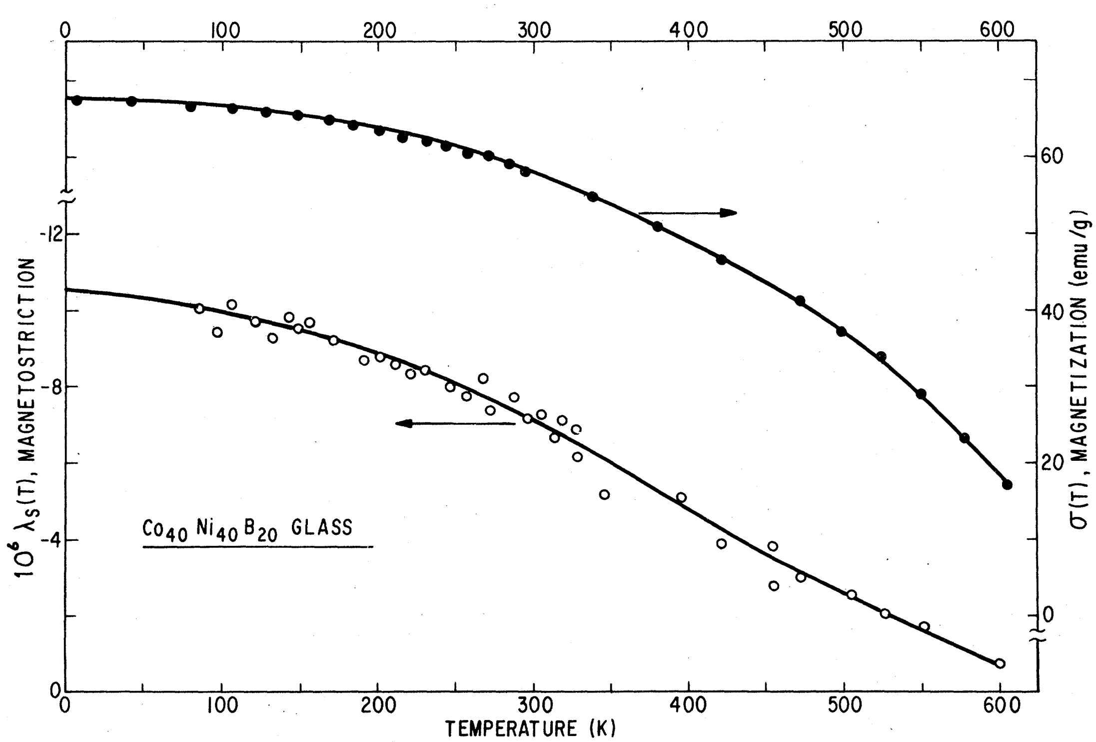


FIG. 4. Magnetostriction (left-hand scale) and magnetization in 8 kOe (right-hand scale) as a function of temperature in $Co_{40}Ni_{40}B_{20}$ glass. Note $\lambda\ (T) < 0$.

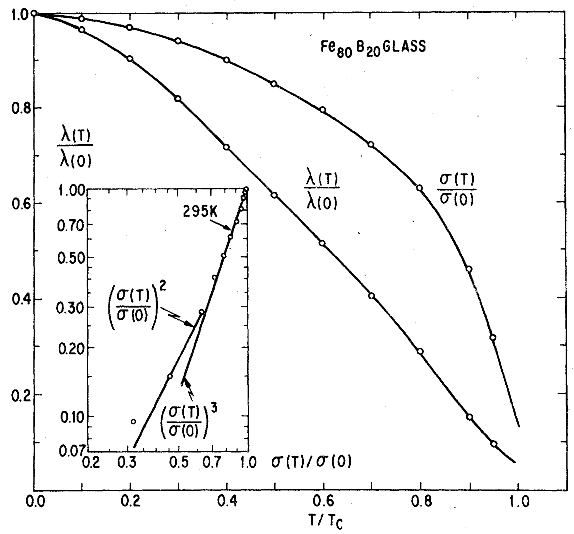


FIG. 5. Magnetostriction and magnetization, normalized to their $T = 0$K values, as a function of $T/T_C$ in $Fe_{80}B_{20}$ glass. Inset shows on a log-log scale the dependence of $\lambda(T)/\lambda(0)$ on $m(T) \equiv \sigma(T)/\sigma(0)$.

for comparison. The error bars associated with the data reflect maximum uncertainty due to scatter in the data points from run to run on a given sample, variations from sample to sample of the same nominal composition, error due to extrapolation of $\lambda(T)$ to $T = 0$ in the Ni- and Co-containing glasses, and instrumental uncertainty. The data show no significant contributions to the magnetostriction from strain associated with values of $l > 2$. Thus, the samples are well characterized as macroscopically isotropic in their magnetostriction: the magnetization direction is a direction of uniaxial strain symmetry. (This is not necessarily the case for anisotropic media.)

The data for all three glasses follow single-ion theory of uniaxial strain symmetry reasonably well over most of the magnetization range.[37] $Fe_{80}B_{20}$ deviates from $\hat{I}_{5/2}(X)$ behavior for $m(T) \lesssim 0.5$ or $T/T_C \gtrsim 0.85$. This may be associated with the strong field dependence shown by magnetic properties of metallic glasses near $T_C$.[36] Only the cobalt-containing metallic glass shows any appreciable tendency toward two-ion magnetostriction behavior although it is within experimental error of the single-ion curve.

Figure 7 displays $\lambda_s(T)$ and $\sigma(T)$ for three Co-rich glasses (magnetization of $Co_{74}Fe_6B_{20}$ glass is essentially the appropriately weighted average of the two magnetization curves shown). Magnetization data are roughly extrapolated beyond $T_X$ to illustrate approximate $T_C$'s. [The best fitting Brillouin function, $S \simeq 2$, suggests $T_C$'s closer to 950 K but the fit is not good. The arguments to follow are not sensitive to the precise nature of the $\sigma(T)$ extrapolation.] The lines drawn through the magnetostriction data illustrate the average, *reversible* trend up to crystallization.

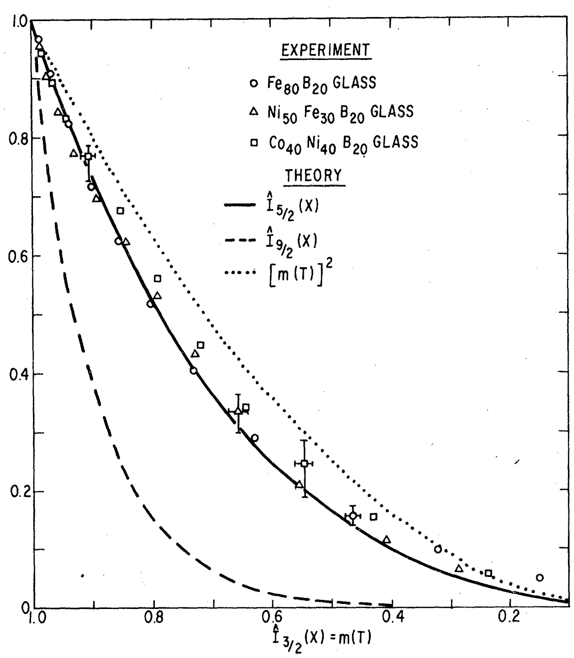


FIG. 6. Observed dependence of reduced magnetostriction on reduced magnetization in three metallic glasses. Theoretical dependences are included for comparison.

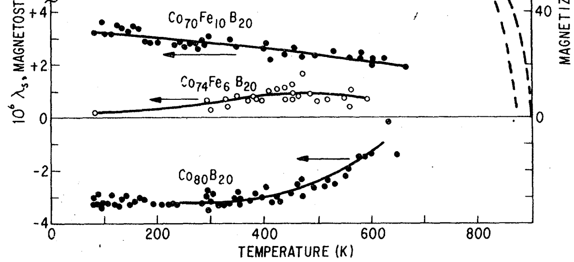


FIG. 7. Temperature dependence of magnetostriction (left-hand scale) and magnetization (right-hand scale) up to crystallization in three cobalt-rich glasses. Magnetization is extrapolated to approximate Curie temperatures (see text).

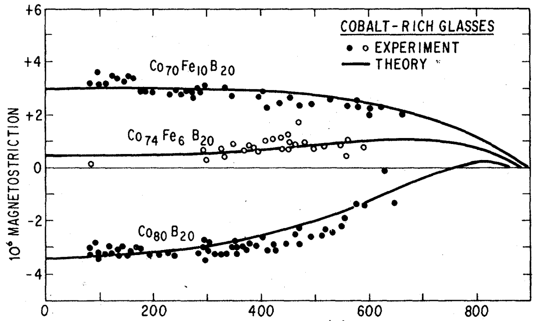


FIG. 8. Magnetostriction data from Fig. 7 compared with theoretical curves (solid lines) which include a two-ion contribution to magnetostriction in cobalt-rich glasses (see Table II).

The marked curvature in $\lambda_s(T)$ for $Co_{80}B_{20}$ glass between 400 and 600 K is greater than would be expected considering the data for $Co_{70}Fe_{10}B_{20}$ glass and the approximate Curie temperatures. In fact, the data suggest a magnetostriction-compensation temperature of approximately 660 K for $Co_{80}B_{20}$ glass.

The behavior shown in Fig. 7 can be explained by assuming the magnetostriction of $Co_{80}B_{20}$ to contain, in addition to a dominant single-ion term, a two-ion component sufficiently small to be consistent with Fig. 6. Because magnetostriction of single-ion origin drops off more rapidly with increasing temperature than does that of two-ion origin, the latter contribution will be proportionately more significant closer to $T_C$. Thus, a magnetostriction of the form

$$\lambda_s(T) = C_1\hat{I}_{5/2}(X) + C_2 m^2 \qquad (3)$$

with $C_1 < 0 < C_2$ and $|C_1| > |C_2|$, will change sign from negative at low temperatures to positive for $T \lesssim T_C$.[38] To describe $\lambda_s(T)$ in the two compositions which contain both Fe and Co, the single-ion terms of $Fe_{80}B_{20}$ and $Co_{80}B_{20}$ must be combined linearly and the two-ion term may vary either quadratically (if only Co-Co anisotropic interactions are important) or linearly (if both Co-Co and Co-Fe anisotropic interactions are important) with cobalt content. The linear variation of two-ion terms [shown in Fig. 8 for the choice of $\lambda_s^{Co}(T) = 6.8\,m^2 - 10.2\hat{I}_{5/2}(X)$] gives a better fit to the data than the quadratic one [for which $\lambda_s^{Co}(T) = 4.6\,m^2 - 8\hat{I}_{5/2}(X)$ is a good choice]. Both theoretical forms show the same general features which mark the data of Fig. 7 as not simply of single-ion origin.[39]

Table II summarizes the results of the present magnetization and magnetostriction measurements. The parentheses around the + two-ion contribution for $Co_{40}Ni_{40}B_{20}$ glass signify the inconclusive nature of the results for that composition (Fig. 6). The last column gives the magnetoelastic coefficients for 0 K. Room-temperature elastic constants of metallic glasses generally increase by less than 5% from room temperature to 0 K.[33,42] This variation, less than the error bars on the data (Fig. 6), would bring the high-temperature data closer to the single-ion curve and would not alter the overall conclusions drawn from the $\lambda_s(T)$ data.

For the sake of comparison, in iron[43] $B_1 \simeq -29 \times 10^6$ erg/cm$^3$ and $B_2 \simeq +32 \times 10^6$ erg/cm$^3$, smaller in magnitude than the value for $Fe_{80}B_{20}$ glass. In nickel,[43] $B_1 \simeq +62 \times 10^6$ erg/cm$^3$ and $B_2 \simeq 90 \times 10^6$ erg/cm$^3$, much stronger than the value for $Ni_{50}Fe_{30}B_{20}$ glass (magnetostriction decreases monotonically on going from $Fe_{80}B_{20}$ glass toward $Ni_{80}B_{20}$ glass).[12,14]

TABLE II. Summary of present results on four metallic glasses: magnetization as a function of temperature (columns 2 and 3) and magnetostriction as a function of temperature (columns 4–6). Magnetoelastic constants (last column) are derived from the equation $B = -\frac{3}{2}\lambda_s(C_{11} - C_{12}) = -\frac{3}{2}\lambda_s E/(1+\nu)$, where $E$ and $\nu$ are Young's modulus and Poisson's ratio, respectively.

| Metallic glass composition (at.%) | $\sigma$(0, 8 kOe) (emu/g) | $T_C$ (K) | $10^6\lambda_s(0)$ | Origin one-ion | Origin two-ion | $C_{11}-C_{12}$ $\left(\frac{10^{12}\text{ erg}}{\text{cm}^3}\right)$ | $B(0)$ $\left(\frac{10^6\text{ erg}}{\text{cm}^3}\right)$ |
|---|---|---|---|---|---|---|---|
| $Fe_{80}B_{20}$ | 190 | 647 | +48 | + | ~0 | 1.28[a] | −94.3 |
| $Co_{80}B_{20}$ | 115 | > 800 | −4 | − | + | 1.33[a] | +7.98 |
| $Co_{40}Ni_{40}B_{20}$ | 67.5 | 610 | −10.5 | − | (+) | ~1.20[b] | +18.9 |
| $Ni_{50}Fe_{30}B_{20}$ | 97.6 | 575 | +12.2 | + | ~0 | ~1.16[c] | −21.2 |

[a]See Refs. 40 and 41.
[b]Extrapolation of results in Ref. 41 gives $E = 14.8 \times 10^3$ kg/mm$^2$ for $Ni_{80}B_{20}$. Assuming $\nu = 0.35$, then $C_{11} - C_{12} = 1.07 \times 10^{12}$ erg/cm$^3$ for $Ni_{80}B_{20}$ and the elastic parameter in the table for $Co_{40}Ni_{40}B_{20}$ may be obtained by averaging those for $Co_{80}B_{20}$ and $Ni_{80}B_{20}$.
[c]$E = 15.8 \times 10^3$ kg/mm$^2$ from Ref. 41 and we assume $\nu \simeq 0.33$.

## V. DISCUSSION

### A. Significance of single-ion behavior

The results shown in Fig. 6 indicate that in TM-M *glasses* the strain derivative of magnetic anisotropy energy (and by implication, the magnetic anisotropy energy itself) arises principally from crystal-field effects and not from anisotropic interatomic interactions. It is reasonable to expect that these two mechanisms would have a similar relative importance in *crystalline* 3*d* metals and alloys. That is, the predominance of single-ion anisotropy over two-ion anisotropic exchange is a characteristic of the transition metal species; it is essentially independent of any nonmagnetic species which may be present as well as of the long-range order of the material. (When the single-ion contribution becomes small as, for example, when $\langle L_z \rangle$ vanishes, the two-ion contribution may be observable. See, e.g., Fig. 8.)

Yosida[44] has argued similarly that the mechanism for magnetic anisotropy in 3*d metals* (which at that time had not been determined) should be essentially the same as is observed in *insulators* (single-ion). This is born out by the present results on metallic, TM-M glasses.

Luborsky and Walter[45] have shown the kinetics and temperature dependence (above 400 K) of the field-induced anisotropy of Fe-Ni base glasses to follow an ordered-pair theory reasonably well, except in the Fe-rich limit. However, their results may also be consistent with the single-ion behavior reported here for the strain derivative of the magnetic anisotropy. This is because, although the anisotropy is of crystal-field origin, field-induced changes in the anisotropy may result from pairs of atoms moving so as to alter the crystal field. A uniaxial, crystal-field anisotropy varies with temperature as $[\sigma(T)/\sigma(0)]^2$ for $T/T_C \gtrsim 0.6$ and therefore cannot be distinguished from an ordered pair anisotropy in this temperature range.

### B. Origin of zero magnetostriction

In *insulating* materials and in rare-earth metals, where electrons that give rise to magnetism are localized, it is possible to describe the ionic states in terms of their atomic wave functions. In these cases, as opposed to 3*d* transition metals and their alloys, theories have been more successful in explaining magnetic anisotropy and magnetostriction.[34,44,46] The magnitude of the anisotropic effects, which are generally attributable to spin-orbit interaction, tends to scale with the expectation value of orbital angular momentum,[47] and to change sign when the low-lying levels pass from less than, to more than, half filled.[48]

Efforts have been made to understand the magnetostriction of 3*d metals* in terms of simple band models.[49,50] More recently, Berger has developed a split-band model[51,52] with which sign changes in magnetostriction are predicted to occur when the Fermi energy passes through the middle of the *d* band of a given species or between the *d* bands (distinct on an energy scale) of two transition elements.[53] The model has been applied successfully to the crystalline Fe-Ni-Cu system.[52]

The split-band model has recently been shown[54] to predict very well the observed path of the $\lambda_s = 0$ line close to the Fe-Ni side (the split-band region) of the triangular $(FeCoNi)_{80}B_{20}$ diagram (Fig. 1). The model associates this line with the passage of the Fermi energy through the boundary between the Ni and Fe $3d^{\downarrow}$ bands.

Inasmuch as it is based on an intra-atomic spin-orbit interaction of the *d* states at $E_F$, the split-band model describes a one-ion magnetostriction. It is to be expected, therefore, that removal of the two-ion magnetostriction component observed in the cobalt-rich glasses would improve the agreement between the predicted and observed $\lambda_s = 0$ lines. Figure 9 shows that this is the case. The slope and intercept of the line joining compositions of zero single-ion magnetostriction (dashed line) is well described by the split-band model (dotted lines) in the split-band (Fe-Ni) regime. The remaining discrepancy on the Fe-Co side of the figure may then be attributed to the inapplicability of the split-band model to the Fe-Co system.

The split-band model suggests, therefore, that

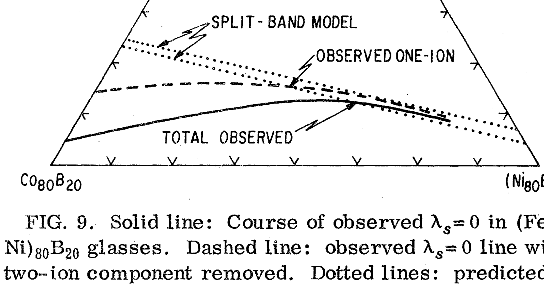


FIG. 9. Solid line: Course of observed $\lambda_s = 0$ in $(FeCoNi)_{80}B_{20}$ glasses. Dashed line: observed $\lambda_s = 0$ line with two-ion component removed. Dotted lines: predicted $\lambda_s = 0$ lines from split-band model for limiting values of charge transfer (see Ref. 54).

the sign change of $\lambda_s$ along the cobalt-nickel side of Fig. 1 is associated with a change in the one-ion orbital character of the $d$ states at the Fermi energy.[55]

## VI. CONCLUSIONS

(i) Magnetoelastic effects in saturated TM-M glasses are isotropic and are, therefore, fully characterized by a single, temperature-dependent coefficient, $\lambda_s^l(T)$ or $B^l(T)$ with $l=2$.

(ii) Measurements of $\lambda_s(T)$ in $Fe_{80}B_{20}$, $Co_{40}Ni_{40}B_{20}$ and $Ni_{50}Fe_{30}B_{20}$ glasses suggest that magnetoelastic effects (and anisotropy) of these glasses are dominated by single-ion mechanisms rather than anisotropic interatomic interactions.

(iii) $\lambda_s(T)$ in cobalt-rich $(FeCo)_{80}B_{20}$ glasses is well described by assuming a positive two-ion contribution in addition to a dominant, negative single-ion contribution.

(iv) A change of sign in $\lambda_s$ occurs near $Co_{75}Fe_5B_{20}$; this is due to a change in the sign of the single-ion term, not the introduction of the two-ion term.

(v) The dominance of one-ion contributions to the anisotropic effects (already recognized in insulators containing transition elements) is probably characteristic of transition metals regardless of the presence or absence of long-ranged structural order or even the presence of a significant fraction of nonmagnetic species (e.g., 20 *at.*%B).

(vi) The sign change in $\lambda_s$ near the cobalt-nickel side of the triangular $(Fe\text{-}Co\text{-}Ni)_{80}B_{20}$ diagram is associated with a change in the one-ion orbital character of the $d$ states at Fermi energy as $E_F$ passes from the top of the Co or Ni $3d^{\downarrow}$ band to the bottom of the Fe $3d^{\downarrow}$ band.

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