Field-induced staggered magnetization and ^{17}O Knight shift anomaly in La_2CuO_4

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We show that the puzzling planar oxygen ^{17}O Knight shift anomalies observed by Walstedt *et al.* [Phys. Rev. Lett. **72**, 3610 (1994); Phys. Rev. B **64**, 014404 (2001)] in paramagnetic phase of generic Dzyaloshinsky-Moriya antiferromagnetic cuprate La_2CuO_4 can be assigned to the effect of the field-induced staggered magnetization.

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I. INTRODUCTION

Starting from pioneer papers by Dzyaloshinsky[1] and Moriya[2] the Dzyaloshinsky-Moriya (DM) antisymmetric exchange coupling was extensively investigated in 60–80ths in connection with weak ferromagnetism focusing on hematite α-Fe_2O_3 and orthoferrites $RFeO_3$.[3] The stimulus to a renewed interest in the subject was given by the cuprate problem, in particular, by the weak ferromagnetism observed in CuO_2 planes of generic cuprate La_2CuO_4 (Ref. 4) and many other interesting effects for the DM systems, in particular, the "field-induced gap" phenomena[5] and field-induced staggered spin polarization. The latter effect, or field-induced antiferromagnetism, was recently observed in copper pyrimidine dinitrate $[CuPM(NO_3)_2(H_2O)_2]_n$, a one-dimensional $S=1/2$ antiferromagnet[6] via a detailed ligand ^{13}C (NMR) study. It is worth noting that well before the ligand NMR was shown to be an effective tool to inspect all the peculiarities of DM coupling in weak ferromagnets.[7] Below we address the effect of the field-induced staggered magnetization in the paramagnetic phase of La_2CuO_4 and its manifestation in the ^{17}O NMR. We show that namely this effect explains the puzzlingly large negative ^{17}O Knight shift for planar oxygens with anisotropy resembled that of weak ferromagnetism which was observed by Walstedt *et al.*[8] The authors made the surprising conclusion that as one approaches T_N, the planar oxygen hyperfine (HF) tensor (i) reverses its sign, (ii) becomes enhanced by well over an order of magnitude, and (iii) exhibits 100% anisotropy. In their opinion these characteristics do not correspond to any known HF mechanism, but are somewhat reminiscent of the functional form of DM exchange coupling. Such an effect has not yet been reported for any other system. The dramatic ^{17}O HF tensor anomaly remains unexplained up to now.[8]

At variance with typical three-dimensional (3D) systems such as orthoferrites or fluorides, cuprates are characterised by a low-dimensionality, large diversity of Cu-O-Cu bonds including corner and edge sharing, different ladder configurations, strong quantum effects for $s=1/2$ Cu^{2+} centers, and a particularly strong Cu-O covalency resulting in a comparable magnitude of hole charge/spin densities on copper and oxygen sites.

II. DZYALOSHINSKY-MORIYA COUPLING AND FIELD-INDUCED STAGGERED MAGNETIZATION

We start with a typical for cuprates three-center (Cu_1-O-Cu_2) two-hole system with tetragonal Cu on-site symmetry and ground Cu $3d_{x^2-y^2}$ states (see Fig. 1) which conventional bilinear spin Hamiltonian is written in terms of copper spins as follows:

$$\hat{H}_s(12) = J_{12}(\hat{\mathbf{s}}_1 \cdot \hat{\mathbf{s}}_2) + \mathbf{D}_{12} \cdot [\hat{\mathbf{s}}_1 \times \hat{\mathbf{s}}_2] + \hat{\mathbf{s}}_1 \overleftrightarrow{\mathbf{K}}_{12} \hat{\mathbf{s}}_2, \qquad (1)$$

where $J_{12}>0$ is an exchange integral, $\mathbf{D}_{12}$ is the Dzyaloshinsky vector, $\overleftrightarrow{\mathbf{K}}_{12}$ is a symmetric second-rank tensor of the anisotropy constants. In contrast with J_{12} and $\overleftrightarrow{\mathbf{K}}_{12}$, the Dzyaloshinsky vector $\mathbf{D}_{12}$ is antisymmetric with regard to the site permutation: $\mathbf{D}_{12}=-\mathbf{D}_{21}$. Usually this vector is assumed to be located on the bond connecting spins 1 and 2, though, strictly speaking, this should be written as a sum of three vectors located on Cu_1, Cu_2, and oxygen sites, respectively: $\mathbf{D}_{12}=\mathbf{D}_{12}^{(1)}+\mathbf{D}_{12}^{(O)}+\mathbf{D}_{12}^{(2)}$. Hereafter we will denote $J_{12}=J, \overleftrightarrow{\mathbf{K}}_{12}=\overleftrightarrow{\mathbf{K}}, \mathbf{D}_{12}=\mathbf{D}$, respectively. It should be noted that making use of effective spin Hamiltonian (1) implies a removal of an orbital degree of freedom that calls for caution with DM coupling as it changes both a spin multiplicity and an orbital state.

For a composite two $s=1/2$ spin system one should consider three types of the vector order parameters:

$$\hat{\mathbf{S}} = \hat{\mathbf{s}}_1 + \hat{\mathbf{s}}_2; \quad \hat{\mathbf{V}} = \hat{\mathbf{s}}_1 - \hat{\mathbf{s}}_2; \quad \hat{\mathbf{T}} = 2[\hat{\mathbf{s}}_1 \times \hat{\mathbf{s}}_2] \qquad (2)$$

with a kinematic constraint:

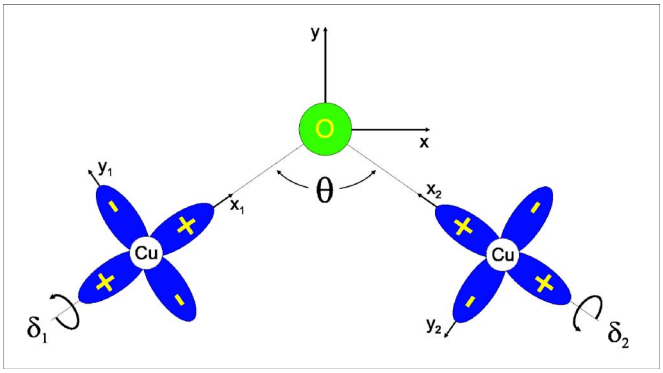

FIG. 1. (Color online) Geometry of the three-center (Cu-O-Cu) two-hole system with ground Cu $3d_{x^2-y^2}$ states.

$$\hat{\mathbf{S}}^2+\hat{\mathbf{V}}^2=3\hat{\mathbf{I}};\quad (\hat{\mathbf{S}}\cdot\hat{\mathbf{V}})=0;\quad (\hat{\mathbf{T}}\cdot\hat{\mathbf{V}})=6i;\quad [\hat{\mathbf{T}}\times\hat{\mathbf{V}}]=\hat{\mathbf{S}}. \tag{3}$$

In a sense the $\hat{\mathbf{V}}$ operator describes the effect of local antiferromagnetic order with $\langle\mathbf{V}\rangle=\mathbf{L}$, or antiferromagnetic vector, while the $\hat{\mathbf{T}}$ operator may be associated with a vector chirality.[9] In recent years, phases with broken vector chirality in frustrated quantum spin chains have attracted considerable interest. Such phases are characterized by nonzero long-range correlations of the vector order parameter $\langle\hat{\mathbf{T}}\rangle$.

Both $\hat{\mathbf{T}}$ and $\hat{\mathbf{V}}$ operators change the spin multiplicity with matrix elements

$$\langle 00|\hat{T}_m|1n\rangle=\langle 1n|\hat{T}_m|00\rangle=i\delta_{mn};$$

$$\langle 00|\hat{V}_m|1n\rangle=\langle 1n|\hat{V}_m|00\rangle=\delta_{mn}, \tag{4}$$

where we made use of Cartesian basis for $S=1$. The eigenstates of the operators $\hat{V}_n$, and $\hat{T}_n$ with nonzero eigenvalues ±1 form Néel doublets $\frac{1}{\sqrt{2}}(|00\rangle\pm|1n\rangle$ and DM doublets $\frac{1}{\sqrt{2}}(|00\rangle\pm i|1n\rangle)$, respectively. The Néel doublets correspond to classical collinear antiferromagnetic spin configurations, while the DM doublets correspond to quantum spin configurations which sometimes are associated with a rectangular 90° spin ordering in the plane orthogonal to the Dzyaloshinsky vector. For an isolated DM coupled antiferromagnetic spin pair we arrive at only the nonzero T-order parameter:

$$\langle\mathbf{S}\rangle=\langle\mathbf{V}\rangle=\mathbf{L}=0;\quad \langle\mathbf{T}\rangle=-\frac{\mathbf{D}}{J}.$$

Interaction of our three-center system with external spins and/or fields $\hat{H}_{ext}$ is usually addressed by introducing only two types of effective external fields: the conventional Zeeman-like field and unconventional Néel-like staggered field, so that $\hat{H}_{ext}$ reads as follows:

$$\hat{H}_{ext}=-(\mathbf{h}^S\cdot\hat{\mathbf{S}})-(\mathbf{h}^V\cdot\hat{\mathbf{V}}). \tag{5}$$

It should be noted that an ideal Néel state is attainable only in the limit of infinitely large staggered field, therefore for a finite staggered field $\mathbf{h}^V\|\mathbf{n}$ the ground state is a superposition of a spin singlet and a Néel state,

$$\Psi=\cos\alpha|00\rangle+\sin\alpha|1n\rangle,\quad \tan 2\alpha=\frac{2h^V}{J},$$

which composition reflects the role of quantum effects. For instance, in a Heisenberg spin 1/2 chain with *nn* exchange the maximal value of staggered field $h^V=J/2$ hence the Ψ function strongly differs from that of Néel state $\left(\langle\hat{V}_n\rangle=\sin 2\alpha=\frac{1}{\sqrt{2}}\right)$, and quantum mechanical average for a single spin $\langle s_z\rangle\leqslant\frac{1}{2}\sin\pi/4=\frac{1}{\sqrt{2}}\cdot\frac{1}{2}\approx0.71\cdot\frac{1}{2}$ deviates strongly from the classical value $\frac{1}{2}$. It should be noted that for the isolated antiferromagnetically coupled spin pair the zero-temperature uniform spin susceptibility turns into zero: $\chi^S=0$, while for the staggered spin susceptibility we obtain $\chi^V=2/J$.

The short analysis of DM-coupled spin pair allows us to turn to the effect of a field-induced staggered magnetization. Indeed, the application of an uniform external magnetic field $\mathbf{h}^S$ will produce a staggered spin polarization in the antiferromagnetically coupled Cu_1-Cu_2 pair

$$\langle\mathbf{V}\rangle=\mathbf{L}=-\frac{1}{J^2}[\mathbf{D}\times\mathbf{h}^S]=\overleftrightarrow{\chi}^{VS}\mathbf{h}^S \tag{6}$$

with antisymmetric *VS*-susceptibility tensor: $\chi^{VS}_{\alpha\beta}=-\chi^{VS}_{\beta\alpha}$. One sees that the direction of field-induced staggered polarization, or antiferromagnetic vector, is perpendicular both to the applied uniform magnetic field and Dzyaloshinsky vector, and its sense depends on that of a Dzyaloshinsky vector.[7] The *VS* coupling results in many interesting effects for the DM systems, in particular, the "field-induced gap" phenomena in a one-dimensional (1D) $s=1/2$ antiferromagnetic Heisenberg system with alternating DM coupling.[5] All these effects can be, approximately, described by a so called *staggered* $s=1/2$ antiferromagnetic Heisenberg model with the effective Hamiltonian (Refs. 5 and 6)

$$\hat{H}=J\sum_i(\hat{\mathbf{s}}_i\cdot\hat{\mathbf{s}}_{i+1})-h_u\hat{s}_{iz}-(-1)^i h_s\hat{s}_{ix}, \tag{7}$$

which includes the effective uniform field h_u and the induced staggered field $h_s\propto h_u$ which is in accordance with Eq. (6) perpendicular both to the applied uniform magnetic field and Dzyaloshinsky vector.

III. FIELD-INDUCED STAGGERED MAGNETIZATION AND ^{17}O NMR IN La_2CuO_4

Earlier on (see Ref. 7) we pointed to the ligand NMR as, probably, the only experimental technique to measure both staggered spin polarization, or antiferromagnetic vector in weak 3D ferromagnets and the value, direction, and the sense of Dzyaloshinsky vector. The latter possibility was realized with ^{19}F NMR for weak ferromagnet FeF_3.[7] Here we address the problem for a generic weak ferromagnetic cuprate La_2CuO_4 making use of ligand ^{17}O NMR as an unique local probe to study the charge and spin densities on oxygen sites.

The DM coupling and magnetic anisotropy in La_2CuO_4 and related compounds has attracted considerable attention in the nineties (see, e.g., Refs. 10–13), and is still debated in the literature.[14,15] In the low-temperature tetragonal (LTT) and orthorhombic (LTO) phases of La_2CuO_4, the oxygen octahedra surrounding each copper ion rotate by a small tilting angle ($\delta_{LTT}\approx3°$, $\delta_{LTO}\approx5°$) relative to their location in the high-temperature tetragonal (HTT) phase. The structural distortion allows for the appearance of the antisymmetric Dzyaloshinsky-Moriya interaction. In terms of our choice for structural parameters to describe the Cu_1-O-Cu_2 bond we have for the LTT phase: $\theta=\pi$; $\delta_1=\delta_2=\frac{\pi}{2}\pm\delta_{LTT}$ for bonds oriented perpendicular to the tilting plane, and $\theta=\pm(\pi-2\delta_{LTT})$; $\delta_1=\delta_2=\frac{\pi}{2}$ for bonds oriented parallel to the tilting plane. It means that all the local Dzyaloshinsky vectors turn into zero for the former bonds, and turn out to be perpendicular to the tilting plane for the latter bonds. For LTO phase: $\theta=\pm(\pi-\sqrt{2}\delta_{LTO})$; $\delta_1=\delta_2=\frac{\pi}{2}\pm\delta_{LTO}$. The largest

($\propto \delta_{LTO}$) component of the local Dzyaloshinsky vectors (z component in our notation) turns out to be oriented perpendicular to the Cu_1-O-Cu_2 bond plane. Other two components of the local Dzyaloshinsky vectors are fairly small: that of perpendicular to CuO_2 plane (y component in our notation) is of the order of δ_{LTO}^2, while that oriented along Cu_1-Cu_2 bond axis (x components in our notation) is of the order of δ_{LTO}^3.

Detailed study of the ligand ^{17}O hyperfine couplings in weak ferromagnetic La_2CuO_4 for temperatures ranging from 285 to 800 K undertaken by Walstedt *et al.*[8] has uncovered puzzling anomalies of the ^{17}O Knight shift. With the approaching transition to the ordered magnetic phase, the authors observed an anomalously large negative ^{17}O Knight shift for planar oxygens of which anisotropy resembled that of weak ferromagnetism in this cuprate. The giant shift was observed only when external field was parallel to the local Cu-O-Cu bond axis (PL1 lines) or perpendicular to CuO_2 plane. The effect was not observed for PL2 lines which correspond to oxygen in the local Cu-O-Cu bonds whose axis is perpendicular to an in-plane external field. It is worth noting once more, that the most part of the experimental data was collected in a paramagnetic state for temperatures well above T_N where there are no frozen moments! The data were first interpreted as an indication of a direct oxygen spin polarization due to a local Dzyaloshinsky-Moriya antisymmetric exchange coupling. However, it demands unphysically large values for such a polarization, hence the puzzle remained unsolved.[8]

Our interpretation of ligand NMR data in such low-symmetry systems as La_2CuO_4 implies a thorough analysis both of spin canting effects and of transferred hyperfine interactions with a revisit of some textbook results being typical for the model high-symmetry systems. First, we start with spin-dipole hyperfine interactions for O $2p$-holes which are main participants of Cu_1-O-Cu_2 bonding. Making use of a conventional formula for a spin-dipole contribution to local field

$$\mathcal{H}_n = -g_s\mu_B \sum_i \frac{3(\mathbf{r}_i\cdot\mathbf{s}_i)\mathbf{r}_i - r_i^2\mathbf{s}_i}{r_i^5},$$

and calculating appropriate matrix elements on oxygen $2p$-functions

$$\left\langle p_i \left| \frac{3x_\alpha x_\beta - r^2\delta_{\alpha\beta}}{r^5} \right| p_j \right\rangle = -\frac{2}{5}\left\langle \frac{1}{r^3}\right\rangle_{2p} \langle p_i|3\widetilde{l_\alpha l_\beta} - 2\delta_{\alpha\beta}|p_j\rangle = \frac{2}{5}\left\langle \frac{1}{r^3}\right\rangle_{2p}\left(\frac{3}{2}\delta_{\alpha i}\delta_{\beta j} + \frac{3}{2}\delta_{\alpha j}\delta_{\beta i} - \delta_{\alpha\beta}\delta_{ij}\right) \quad (8)$$

we present a local field on the ^{17}O nucleus in the Cu_1-O-Cu_2 system as a sum of ferro- and antiferromagnetic contributions as follows (Ref. 7):

$$\mathcal{H}_n = \vec{\mathbf{A}}^S\cdot\langle\hat{\mathbf{S}}\rangle + \vec{\mathbf{A}}^V\cdot\langle\hat{\mathbf{V}}\rangle \quad (9)$$

where

$$\vec{\mathbf{A}}^S = \vec{\mathbf{A}}^S(dp) + \vec{\mathbf{A}}^S(pd); \quad \vec{\mathbf{A}}^V = \vec{\mathbf{A}}^V(pd) - \vec{\mathbf{A}}^V(dp),$$

$$A_{ij}^S(dp) = A_p^{(0)}[3c_t(dp_i)c_t(dp_j) - |\mathbf{c}_t(dp)|^2\delta_{ij}],$$

$$A_{ij}^S(pd) = A_p^{(0)}[3c_t(p_id)c_t(p_jd) - |\mathbf{c}_t(pd)|^2\delta_{ij}],$$

$$A_{ij}^V(dp) = A_p^{(0)}[3\widetilde{c_s(dp_i)c_t(dp_j)} - (\mathbf{c}_s(dp)\cdot\mathbf{c}_t(dp))\delta_{ij}],$$

$$A_{ij}^V(pd) = A_p^{(0)}[3\widetilde{c_s(p_id)c_t(p_jd)} - (\mathbf{c}_s(pd)\cdot\mathbf{c}_t(pd))\delta_{ij}],$$

where

$$c_{s,t}(dp_x) = -\frac{\sqrt{3}}{2}\frac{t_{dp\sigma}}{E_{s,t}(dp_x)}\sin\frac{\theta}{2},$$

$$c_{s,t}(dp_y) = -\frac{\sqrt{3}}{2}\frac{t_{dp\sigma}}{E_{s,t}(dp_y)}\cos\frac{\theta}{2} \quad (10)$$

are probability amplitudes for different singlet (c_s) and triplet (c_t) 110 ($Cu_1 3d_{x^2-y^2} O2p_{x,y}$) and 011 ($O2p_{x,y}Cu_2 3d_{x^2-y^2}$) configurations in the ground state wave function, respectively; $c_{s,t}(dp_x) = -c_{s,t}(p_xd)$, $c_{s,t}(dp_y) = c_{s,t}(p_yd)$, $t_{dp\sigma}$ is a hole dp-transfer integral, $A_p^{(0)} = \frac{2}{5}g_s\mu_B\left\langle\frac{1}{r^3}\right\rangle_{2p}$, the tilde points to a symmetrization. The energies $E_{s,t}(dp_{x,y})$ are those for singlet and triplet states of $dp_{x,y}$ configurations, respectively: $E_{s,t}(dp_{x,y}) = \epsilon_{x,y} + K_{dpx,y} \pm I_{dpx,y}$, where $K_{dpx,y}$ and $I_{dpx,y}$ are Coulomb and exchange dp-integrals, respectively. Thus, along with a conventional textbook ferromagnetic ($\propto\langle\hat{\mathbf{S}}\rangle$) transferred hyperfine contribution to local field which simply mirrors a sum total of two Cu-O bonds, we arrive at an additional unconventional antiferromagnetic difference ($\propto\langle\hat{\mathbf{V}}\rangle$) contribution which symmetry and magnitude strongly depend on the orientation of the oxygen crystal field axes and Cu_1-O-Cu_2 bonding angle. In the case of Cu_1-O-Cu_2 geometry shown in Fig. 1 we arrive at a diagonal $\vec{\mathbf{A}}^S$ tensor:

$$A_{xx}^S = 2A_p\left(3\sin^2\frac{\theta}{2} - 1\right); \quad A_{yy}^S = 2A_p\left(3\cos^2\frac{\theta}{2} - 1\right);$$

$$A_{zz}^S = -2A_p, \quad (11)$$

and the only nonzero components of $\vec{\mathbf{A}}^V$ tensor:

$$A_{xy}^V = A_{yx}^V = 3A_p\sin\theta \quad (12)$$

with

$$A_p = \frac{3}{4}\left(\frac{t_{dp\sigma}}{\epsilon_p}\right)^2 A_p^0 = f_\sigma A_p^0, \quad (13)$$

where f_σ is the parameter of a transferred spin density and we made use of a simple approximation $E_{s,t}(dp_{x,y}) \approx \epsilon_p$.[16] Thus, the ligand ^{17}O NMR provides an effective tool to inspect the spin canting effects in oxides with DM coupling both in paramagnetic and ordered phases.

The two-term structure of oxygen local field implies a two-term S-V structure of the ^{17}O Knight shift

$$^{17}K = \overleftrightarrow{\mathbf{A}}^{S}\overleftrightarrow{\chi}^{SS} + \overleftrightarrow{\mathbf{A}}^{V}\overleftrightarrow{\chi}^{VS} \tag{14}$$

that points to the Knight shift as an effective tool to inspect both uniform and staggered spin polarization. The existence of an antiferromagnetic term in oxygen hyperfine interactions yields a rather simple explanation of the ^{17}O Knight shift anomalies in La_2CuO_4[8] as a result of the external field-induced staggered spin polarization $\langle\hat{\mathbf{V}}\rangle = \mathbf{L} = \overleftrightarrow{\chi}^{\mathbf{VS}}\mathcal{H}_{\mathbf{ext}}$. Indeed, "our" local y axis for Cu_1-O-Cu_2 bond corresponds to the crystal tetragonal c axis oriented perpendicular to CuO_2 planes both in LTO and LTT phases of La_2CuO_4 while the x axis does to the local Cu-O-Cu bond axis. It means that for the geometry of the experiment by Walstedt *et al.*[8] (the crystal is oriented so that the external uniform field is either $\parallel$ or $\perp$ to the local Cu-O-Cu bond axis) the antiferromagnetic contribution to ^{17}O Knight shift will be observed only (i) for oxygen in Cu_1-O-Cu_2 bonds oriented along external field or (ii) for external field along the tetragonal c axis. Experimental data[8] agree with staggered magnetization along the tetragonal c axis in the former and along the rhombic c axis (tetragonal ab axis) in the latter. Given $L=1$, $A_p^{(0)} \approx 100$ kG/spin,[8] $|\sin\theta| \approx 0.1$, and $f_\sigma \approx 20\%$ we obtain ≈ 6 kG as a maximal value of a low-temperature antiferromagnetic contribution to the hyperfine field which is equivalent to a giant ^{17}O Knight shift of the order of almost $\sim 10\%$. Nevertheless, this value agrees with a low-temperature extrapolation of high-temperature experimental data by Walstedt *et al.*[8] Interestingly, the sizeable effect of anomalous negative contribution to the ^{17}O Knight shift has been observed in La_2CuO_4 well inside the paramagnetic state for temperatures $T \sim 500$ K that is essentially higher than $T_N \approx 300$ K. It points to the close relation between the magnitude of field-induced staggered magnetization and spin-correlation length which goes up as one approaches T_N.

The ferroantiferromagnetic S-V structure of local field on the nucleus of an intermediate oxygen ion in a Cu_1-O-Cu_2 triad points to ^{17}O NMR as, probably, the only experimental technique to measure both the value, direction, and the sense of a Dzyaloshinsky vector. For instance, the negative sign of ^{17}O Knight shift in La_2CuO_4[8] points to a negative sign of $\overleftrightarrow{\chi}^{VS}$ for a Cu_1-O-Cu_2 triad with $A^V_{xy} > 0$, hence to a positive sense of z component of the summary Dzyaloshinsky vector in a Cu_1-O-Cu_2 triad with geometry shown in Fig. 1 given $\theta \leqslant \pi$, $\delta_1 = \delta_2 \approx \pi/2$. It should be emphasized that the above effect is determined by the summary Dzyaloshinsky vector in Cu_1-O-Cu_2 triad rather than by a local oxygen "weak-ferromagnetic" polarization as it was first proposed by Walstedt *et al.*[8]

A similar effect of anomalous ligand ^{13}C Knight shift has recently been observed in copper pyrimidine dinitrate $[CuPM(NO_3)_2(H_2O)_2]_n$, a one-dimensional $S=1/2$ antiferromagnet with alternating local symmetry, and was also interpreted in terms of the field-induced staggered magnetization.[6] However, the authors did take into account only the intersite magnetodipole contribution to $\overleftrightarrow{\mathbf{A}}^{V}$ tensor that questions their quantitative conclusions regarding the "giant" spin canting.

In conclusion, we predict the effect of the field-induced staggered magnetization in a paramagnetic state of the weak ferromagnetic cuprate La_2CuO_4. The planar oxygen ^{17}O Knight shift is shown to be an effective tool to inspect the effects of Dzyaloshinsky-Moriya coupling in cuprates in an external magnetic field. Field-induced staggered magnetization and anisotropic antiferromagnetic contribution to ^{17}K explain the anomalies observed by Walstedt *et al.* in ^{17}O NMR in La_2CuO_4.[8] It is worth noting that their work may be addressed to be a first observation of the field-induced staggered magnetization. The experimental observation of antiferromagnetic contribution to the ^{17}O Knight shift provides probably the only way to find out the problem of the sense of the Dzyaloshinsky vector in cuprates.

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[16] Generally speaking, we should take into account an additional contribution of magnetodipole hyperfine interactions.