

Evolution of the 1/9 magnetization plateau in the kagome system $\text{YCu}_3(\text{OH})_6[(\text{Cl}_x\text{Br}_{1-x})_{3-y}(\text{OH})_y]$

Guoxin Zheng,¹ Yuan Zhu,¹ Noah West¹,¹ Kaila Jenkins¹,¹ Dechen Zhang,¹ Kuan-Wen Chen,¹ Aaron Chan¹,¹
 Zhenyuan Zeng,^{2,3} Aini Xu,^{2,3} Oscar A. Valenzuela,⁴ Joanna Blawat⁴,⁴ John Singleton⁴,⁴
 Patrick A. Lee,⁵ Shiliang Li,^{2,3,6} and Lu Li^{1,*}

¹*Department of Physics, University of Michigan, Ann Arbor, Michigan 48109, USA*

²*Beijing National Laboratory for Condensed Matter Physics, Institute of Physics, Chinese Academy of Sciences, Beijing 100190, China*

³*School of Physical Sciences, University of Chinese Academy of Sciences, Beijing 100190, China*

⁴*National High Magnetic Field Laboratory, MS E536, Los Alamos National Laboratory, Los Alamos, New Mexico 87545, USA*

⁵*Department of Physics, Massachusetts Institute of Technology, Cambridge, Massachusetts 02139, USA*

⁶*Songshan Lake Materials Laboratory, Dongguan, Guangdong 523808, China*



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The 1/9 magnetization plateau has recently been observed in the spin-1/2 kagome Heisenberg antiferromagnet (KHA) $\text{YCu}_3(\text{OH})_6\text{Br}_2[\text{Br}_{1-y}(\text{OH})_y]$ (YCOB), a promising quantum spin liquid (QSL) candidate. However, the 1/9 plateau has so far been reported only in YCOB, and its microscopic origin and low-energy nature remain under debate. In this study, we investigate the magnetic properties of the chlorine-substituted series $\text{YCu}_3(\text{OH})_6[(\text{Cl}_x\text{Br}_{1-x})_{3-y}(\text{OH})_y]$ (YCOB-Cl) and track the evolution of the 1/9 magnetization plateau across the doping series. We observe clear signatures of the 1/9 plateau at multiple nominal Cl concentrations. The temperature dependence of the plateau response evolves systematically with increasing x , consistent with a progressive suppression of low-energy spectral weight and the emergence of a possible effective gap scale. Complementary magnetic torque measurements further show that the magnetic oscillations accompanying the plateau are present only in the $x = 0$ sample, indicating that chemical substitution strongly affects the low-energy states associated with the plateau. Taken together, our results establish YCOB-Cl as a tunable platform for exploring how chemical disorder and modified exchange networks reshape the 1/9 plateau and its associated anomalous magnetic responses.

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I. INTRODUCTION

The search for quantum spin liquids (QSLs) has been one of the most intensively studied areas since Anderson's proposal of the resonating-valence-bond (RVB) model in 1973 [1], due to its pivotal role in understanding high-temperature superconductivity [2] and the realization of topological quantum computation [3]. Among the many efforts to discover QSLs, the spin-1/2 kagome Heisenberg antiferromagnet (KHA) appears to be an excellent candidate, owing to its high degree of frustration and robust QSL behavior in unbiased density matrix renormalization (DMRG) calculations [4–8]. In addition to the zero-field QSL state, an external magnetic field can induce an unconventional 1/9 magnetization plateau in KHA which may represent a topological $\mathbb{Z}_3$ QSL [6] or a valence bond crystal (VBC) [9]. This plateau is particularly intriguing because it differs from the higher-field 1/3, 5/9, and 7/9 plateaus commonly associated with magnon-crystal states [8,10,11].

Recently, a new KHA $\text{YCu}_3(\text{OH})_6\text{Br}_2[\text{Br}_{1-y}(\text{OH})_y]$ (YCOB) has attracted considerable attention due to its perfect kagome plane and absence of magnetic order down to 50 mK [12–14], making it a promising QSL candidate.

One exciting discovery is the emergence of an unusual 1/9 magnetization plateau under an applied magnetic field of 20 T [15–18], though its origin remains unclear. Proposed explanations include the formation of fractionalized spinons [15], and the gapped $\mathbb{Z}_3$ QSL or VBC [17]. A recent heat-capacity study indicates that this plateau is gapless and exhibits signatures of Dirac spinons [18]. Moreover, unusual magnetic oscillations following the 1/9 magnetization plateau have been observed in magnetic torque measurements, as reported in Ref. [15]; these are a key feature predicted by the Dirac spin liquid (DSL) model [19,20]. The effect of replacing partial Br^- with Cl^- in YCOB has been studied in $\text{YCu}_3(\text{OH})_6[(\text{Cl}_x\text{Br}_{1-x})_{3-y}(\text{OH})_y]$ (YCOB-Cl) [21–23]. By introducing Cl^- , the DSL ground state in the $x = 0$ case is replaced by long-range antiferromagnetic (AFM) order when $x > 0.5$, where uniform hexagons dominate [21]. These findings indicate that the bond randomness resulting from substitution between Br^- (Cl^-) and OH^- has a significant influence on the ground state of YCOB-Cl [21,22,24]. However, the relationship between these low-field features and 1/9 magnetization plateau has not been studied. Furthermore, understanding the evolution of the 1/9 plateau across different doping levels is crucial for unraveling the nature of this unconventional magnetization plateau. In this work, we have studied the magnetic properties of the KHA system YCOB-Cl using magnetization M and magnetic torque τ measurements

*Contact author: luli@umich.edu

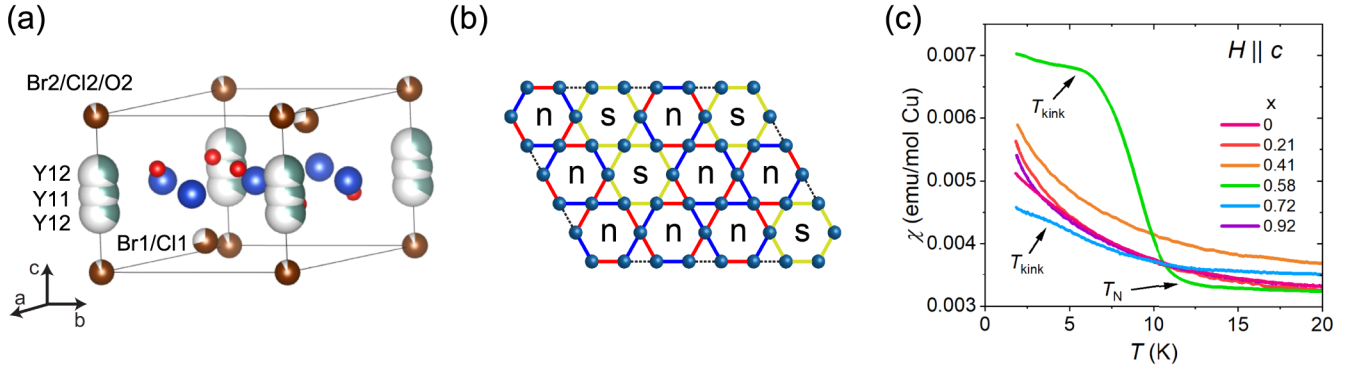


FIG. 1. Structure and magnetic properties of YCOB-Cl. (a) The crystal structure of YCOB-Cl where hydrogens are not shown. (b) Sketch of the bond-randomness model. The uniform hexagons (s) have the same exchange energy J (yellow), while the alternate-bond hexagons (n) have $J + \Delta J$ (red) and $J - \Delta J$ (blue). (c) The temperature dependence of the magnetic susceptibility, χ , for samples with different x , measured at 0.1 T with $H \parallel c$ under field-cooled conditions. T_N and T_{kink} are discussed in the main text.

under applied magnetic fields $\mu_0 H$ of up to 59 T, with the chlorine-doping level (x) ranging from 0 to 0.92. We observed the emergence of the $1/9$ magnetization plateau for $0 \leq x \leq 0.41$ and $x = 0.92$. An analysis of the temperature dependence shows that the $x = 0$ plateau is better described by a gapless spinon phenomenology, whereas the Cl-doped samples are more consistent with an activated response and the emergence of a possible effective gap scale. Consistently, the magnetic oscillations resolved in torque are observed only for $x = 0$, indicating that the low-energy states associated with the plateau are strongly suppressed at higher Cl concentrations.

II. LOW-FIELD MAGNETIZATION

Figure 1(a) shows the crystal structure of YCOB-Cl, with corresponding parameters provided in Table I and in Ref. [21]. In YCOB-Cl, the substitution of Cl^- for Br^- is represented by x , whilst that of OH^- for Br^- (Cl^-) is represented by y . The latter substitution leads to two inequivalent positions for the Y atom, namely, Y11 and Y12 [13,21]. This local distortion influences the nearest-neighbor (NN) exchange coupling constant J , and recent density functional theory (DFT) calculations show that the symmetric-nonsymmetric environment model effectively captures the properties of YCOB [13]. As shown in Fig. 1(b), the symmetric environment (s) refers to the uniform hexagons (UH) in the kagome plane, formed by Cu^{2+} ions with Y11 at the center, characterized by a uniform exchange energy J , depicted by yellow bonds. In contrast, the nonsymmetric environment (n) corresponds to alternate-bond

hexagons (ABH) in the kagome lattice, with Y12 positioned off center, leading to two different exchange energies, $J + \Delta J$ (red bonds) and $J - \Delta J$ (blue bonds). In other words, randomness in the Y-site configuration introduces a corresponding randomness in the exchange energy. The value of ΔJ is estimated to be $0.7J$, where J is approximately 60 K in YCOB [13]. However, the strength of bond-disorder ΔJ is still under debate [21]. One notable observation is that the intermediate doping range (e.g., $x = 0.58$) appears to exhibit a more uniform bond structure (Table I), which requires further study to clarify its microscopic origin. With Cl^- doping, the Curie temperature generally increases with higher doping levels, and the ratio of $n/(n + s)$ changes as well [21], making the evolution of the magnetic properties rather complex, as we will discuss in the following part.

Figure 1(c) shows the temperature (T) dependence of the magnetic susceptibility (χ) across various doping levels with $\mu_0 H = 0.1$ T applied along the c axis under field-cooled conditions. No magnetic transitions were observed for $x = 0, 0.21, 0.41$, and 0.92 down to 2 K. Evidence for QSL behavior from heat-capacity data has been reported for these samples in Ref. [21], where it is closely linked to the degree of disorder. Thus, we classify these doping levels as hosting disorder-stabilized spin liquid (DSSL) in this study. By contrast, χ increases rapidly below $T_N \approx 11$ K for $x = 0.58$, indicating the formation of antiferromagnetic (AFM) order below T_N . χ gradually saturates below T_{kink} ; a divergence between the field- and zero-field-cooled curves below T_{kink} was reported in Ref. [21], suggesting long-range AFM order

TABLE I. Refined structure information of YCOB-Cl by SCXRD at 300 K, reported in Ref. [21]. x_n is the nominal Cl content. x is the measured Cl content. The space group for all the samples is $P\bar{3}m1$. The occupancies of unlisted elements, i.e., Cu and O1, are 1.

x_n	x	a (Å)	c (Å)	Y11	Y12	Cl1	Br1	Cl2	Br2	O2
0	0	6.6784(2)	5.9901(3)	0.301(2)	0.3493(12)	0	1	0	0.326(6)	0.674(6)
0.10	0.212	6.6783(3)	5.9684(3)	0.3201(19)	0.3399(10)	0	1	0.58(3)	0.158(11)	0.26(2)
0.35	0.407	6.6771(6)	5.9041(9)	0.344(2)	0.3279(10)	0.246(8)	0.754(8)	0.59(3)	0.049(11)	0.36(2)
0.50	0.584	6.7439(10)	5.7745(11)	0.82(2)	0.090(11)	0.385(11)	0.615(11)	0.97(3)	0.006(13)	0.03(2)
0.70	0.723	6.6832(3)	5.7967(3)	0.3848(16)	0.3076(8)	0.623(6)	0.377(6)	0.713(17)	0	0.287(17)
0.9	0.924	6.664(4)	5.7540(6)	0.353(3)	0.323(1)	0.902(7)	0.099(7)	0.673(25)	0.005(8)	0.322(20)

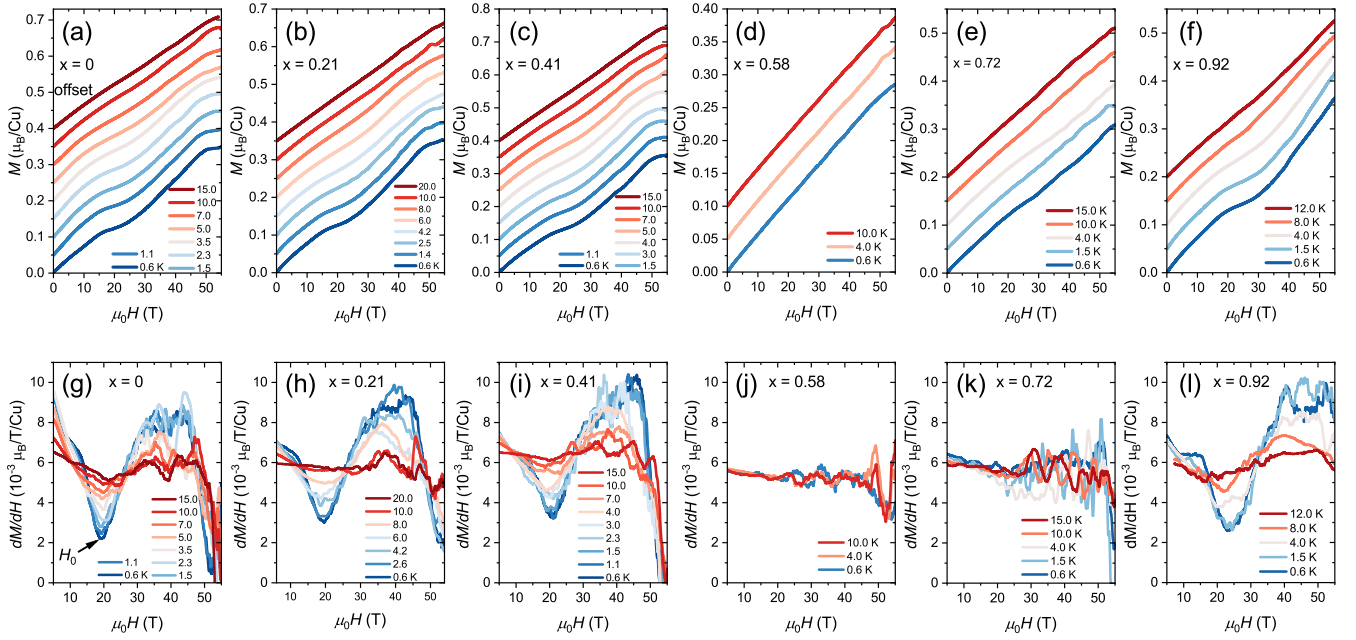


FIG. 2. High-field magnetic properties of YCOB-Cl. (a)–(f) Temperature dependence of the magnetization M for fields $B \parallel c$ up to 55 T at different Cl-doping levels, $x = 0$ (a), 0.21 (b), 0.41 (c), 0.58 (d), 0.72 (e), and 0.92 (f). Curves are vertically offset for clarity. (g)–(l) The corresponding temperature evolution of magnetic susceptibility $\chi = dM/dH$ for $x = 0$ (g), 0.21 (h), 0.41 (i), 0.58 (j), 0.72 (k), and 0.92 (l). H_0 in (g) labels the minimum value of χ inside the 1/9 plateau region.

or spin freezing. The signature of T_N is rather weak in the $x = 0.72$ case, but T_{kink} can still be identified below ≈ 3.5 K. We therefore classify $x = 0.58$ and 0.72 samples as exhibiting long-range order (LRO).

III. HIGH-FIELD MAGNETIZATION

After studying the low-field magnetic properties of YCOB-Cl, we extended our measurements to fields of up to 55 T to evaluate the evolution of the 1/9 magnetization plateau, previously only reported for $x = 0$ [15–17]. Details of the magnetometry technique are given in Sec. A of the Supplemental Material (SM) [25] (see also Refs. [26,27] therein). Figure 2 displays the overall magnetic-field dependence of the magnetization and magnetic susceptibility ($\chi = dM/dH$) for all Cl-doped samples, with $H \parallel c$ under different temperatures. Clear 1/9 (where $M \approx 0.11 \mu_B/\text{Cu}$, $\mu_0 H \sim 20$ T) and 1/3 (where $M \approx 0.33 \mu_B/\text{Cu}$, $\mu_0 H \sim 50$ T) magnetization plateaus appear for $x = 0, 0.21, 0.41$, and 0.92 (see Fig. S1 in the SM [25] for the 1/3 plateau of $x = 0.92$), and are gradually smeared out by increasing temperature. H_0 in Fig. 2(g) marks the field at which χ reaches its minimum within the 1/9 magnetization plateau region. By contrast, the 1/9 plateau is absent for the ordered compositions $x = 0.58$ and 0.72 , as shown by the featureless $\chi(H)$ near 20 T in Figs. 2(j) and 2(k), indicating that the LRO samples differ from the DSSL samples not only at zero field but also in high fields.

To gain further insight into the 1/9 magnetization plateau, we plot in Fig. 3(a) the field dependence of the susceptibility χ at the lowest temperature for all x values, taking the data from Figs. 2(g)–2(l). The triangles in Fig. 3(a) mark the field location of the minimum value of χ within the 1/9 plateau,

denoted by H_0 . The values of H_0 for different doping levels (x) are shown as red diamonds in Fig. 3(c). The slight increase in H_0 with higher x is consistent with the evolution of J that was inferred from the Curie temperatures [21], as the 1/9 plateau is predicted to emerge at a field corresponding to $\approx 0.3J$ [8].

To investigate the temperature evolution of the 1/9 magnetization plateau observed in YCOB-Cl DSSL samples, we compile the temperature dependence of χ at the plateau minimum field H_0 from Figs. 2(g)–2(i), and 2(l), and plot them as different colored symbols in Fig. 3(b). For clarity, constant offsets are applied to different datasets. We then analyze $\chi(T, H_0)$ using both a gapless phenomenological model and an activated (gapped) form to assess the low-energy nature of the 1/9 plateau.

A. Gapless model fitting on 1/9 plateau

A fermionic gapless model was proposed in Ref. [15] to describe the temperature evolution of the 1/9 plateau in the $x = 0$ sample. Here we adopt this model and briefly summarize the key steps. We start from a simple V-shaped model for $\chi(H)$ at $T = 0$, defined in the inset of Fig. 3(c), which captures the minimum of χ inside the 1/9 plateau around H_0 in Fig. 3(a). In this construction, H_0 denotes the field position of the minimum, H_p is the half-width of the V-shaped minimum, $\chi_c \equiv \chi(H_0, T = 0)$ is the minimum susceptibility at $T = 0$, and χ_p characterizes the relative amplitude of the minimum. Physically, the V-shaped form may represent the field dependence expected for a Dirac node when the chemical potential is shifted by the Zeeman energy [15]. An analytical expression for $\chi(T, H_0)$ can be obtained exactly; here we present only the final result for the temperature dependence of the minimum at

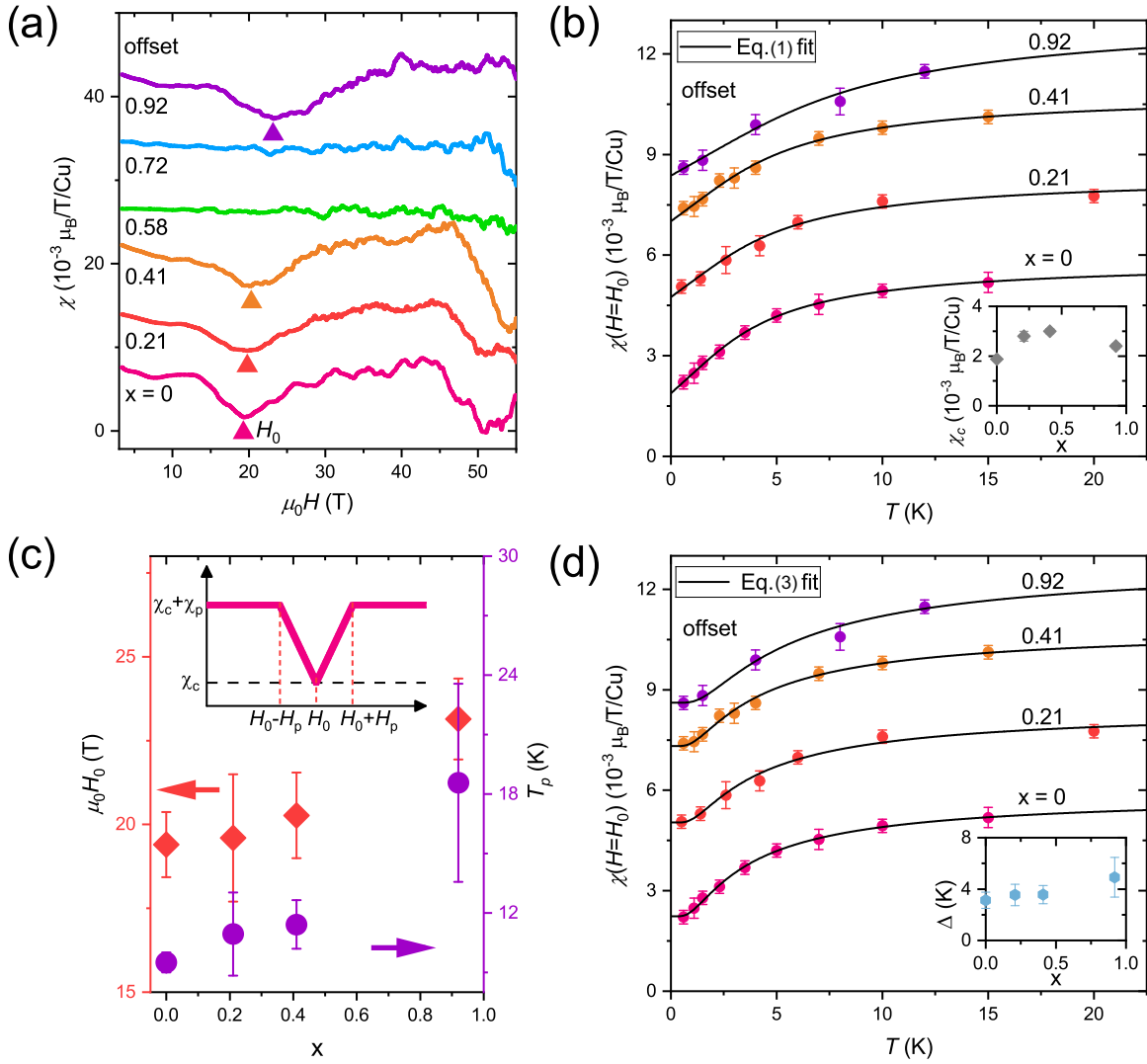


FIG. 3. The evolution of the 1/9 magnetization plateau in YCOB-Cl. (a) Field dependence of $\chi = dM/dH$ at the lowest measured temperature for different Cl-doping levels. Curves are taken from Fig. 2 and shifted for clarity. Triangles mark the minimum position H_0 inside the 1/9 plateau region. (b) Temperature dependence of $\chi(H = H_0)$ for samples showing 1/9 plateau. Solid curves are fits to the gapless model in Eq. (1). Curves are shifted by $2 \times 10^{-3} \mu_B/T/\text{Cu}$ for clarity. The inset shows the fitted χ_c as a function of x . (c) Red diamonds show H_0 extracted from (a), and blue dots show the fitted T_p from (b). Inset: schematic V-shaped gapless model for $\chi(H)$ near H_0 . (d) Temperature dependence of $\chi(H = H_0)$ fitted by the activated form in Eq. (3). The inset shows the fitted effective gap scale Δ as a function of x . The fitting parameters in (b) and (d) are listed in Table II.

H_0 , while the derivation is provided in the SM [25]:

$$\chi(T, H_0) = \chi_c + \chi_p \left[1 + \frac{T}{T_p} \ln \left(\frac{2}{1 + \cosh\left(\frac{T_p}{T}\right)} \right) \right], \quad (1)$$

where $T_p = g\mu_B\mu_0 H_p/2k_B$ is a characteristic temperature scale. By definition, T_p corresponds to the temperature at which the amplitude of the 1/9 minimum in χ is reduced by 76% compared to the $T \rightarrow 0$ limit (see Fig. S2 in the

TABLE II. Fitting parameters for the temperature dependence of $\chi(H = H_0)$. The gapless model in Eq. (1) is used for Fig. 3(b), and the activated model in Eq. (3) is used for Fig. 3(d). The goodness of fit is quantified by R_p .

x	Equation (1) fitting results				Equation (3) fitting results			
	$\chi_c (10^{-3} \mu_B/T/\text{Cu})$	$\chi_p (10^{-3} \mu_B/T/\text{Cu})$	T_p (K)	R_p	$\chi_0 (10^{-3} \mu_B/T/\text{Cu})$	$\chi_A (10^{-3} \mu_B/T/\text{Cu})$	Δ (K)	R_p
0	1.88(23)	3.95(32)	9.6(23)	0.147	2.24(19)	3.64(30)	3.13(63)	0.227
0.21	2.75(21)	3.63(30)	10.9(29)	0.547	3.04(18)	3.40(29)	3.54(83)	0.512
0.41	3.09(20)	3.80(32)	12.2(31)	0.384	3.40(17)	3.50(28)	3.83(77)	0.380
0.92	2.33(24)	4.09(54)	14.1(58)	0.647	2.61(19)	3.85(47)	4.37(14)	0.629

SM [25]). A detailed explanation of Eq. (1) is provided in Sec. B of the SM. We fit the data by minimizing the weighted residual

$$R_p = \sqrt{\frac{1}{N} \sum_i \left(\frac{X_i^{\text{obs}} - X_i^{\text{cal}}}{\sigma_i^{\text{obs}}} \right)^2}, \quad (2)$$

where N is the number of data points, X_i^{obs} and σ_i^{obs} are the measured value and its standard deviation, and X_i^{cal} is the calculated value. The black curves in Fig. 3(b) show fits to samples with different x using Eq. (1). The fitted parameters χ_c , χ_p , and T_p are summarized in Table II; for example, for $x = 0$ we obtain $\chi_c = 1.88(23) \times 10^{-3} \mu_B/\text{T}/\text{Cu}$, $\chi_p = 3.95(32) \times 10^{-3} \mu_B/\text{T}/\text{Cu}$, and $T_p = 9.6(23) \text{ K}$. Furthermore, the x dependence of T_p is shown as blue dots in Fig. 3(c). The gradual increase of T_p with increasing x indicates that the characteristic scale associated with the 1/9 minimum in χ grows with x , consistent with the expectation that the plateau width is primarily set by the exchange scale J [8]. We also note that the x dependences of H_0 and T_p are similar, as both are closely tied to J .

B. Gapped model fitting on the 1/9 plateau

To estimate a possible excitation-gap scale associated with the 1/9 plateau, we also analyze $\chi(T, H_0)$ using a simplified activated form commonly employed for gapped magnetic excitations [28]:

$$\chi(T, H_0) = \chi_0 + \chi_A e^{-\Delta/T}, \quad (3)$$

where χ_0 is the $T \rightarrow 0$ intercept, χ_A is an amplitude, and Δ denotes an effective gap scale (expressed in kelvin). The corresponding fits for different x are shown as black curves in Fig. 3(d), and the fitted parameters are listed in Table II. The extracted values of Δ are plotted in the inset of Fig. 3(d), showing an increasing trend from 3.13 K to 4.37 K as x increases from 0 to 0.92.

Finally, we compare the fitting quality of the two models. For $x = 0$, the low-temperature data in Fig. 3(b) display an approximately linear variation between 0.6 K and 1.5 K, which is captured more naturally by the gapless form in Eq. (1). In contrast, the activated form in Eq. (3) yields a noticeably reduced slope at the lowest temperatures. This preference is also reflected in the goodness-of-fit metric: for $x = 0$, the fit using Eq. (1) gives $R_p = 0.147$, which is significantly smaller than $R_p = 0.227$ obtained from Eq. (3). For $x = 0.21$, $x = 0.41$, and $x = 0.92$, the fits using Eq. (3) yield slightly smaller R_p values than those using Eq. (1), suggesting that an activated (gapped) description may be more appropriate for these samples within the accessible temperature window. We emphasize that higher data quality and additional measurements below 2 K will be needed to reach a definitive conclusion regarding the presence or absence of a small gap.

IV. HIGH-FIELD MAGNETIC TORQUE

Magnetic torque measurements were also conducted in high fields to probe the finer structure beyond the 1/9 magnetization plateau, leveraging the sensitivity of the torque technique [29]. The field dependence of magnetic torque (τ)

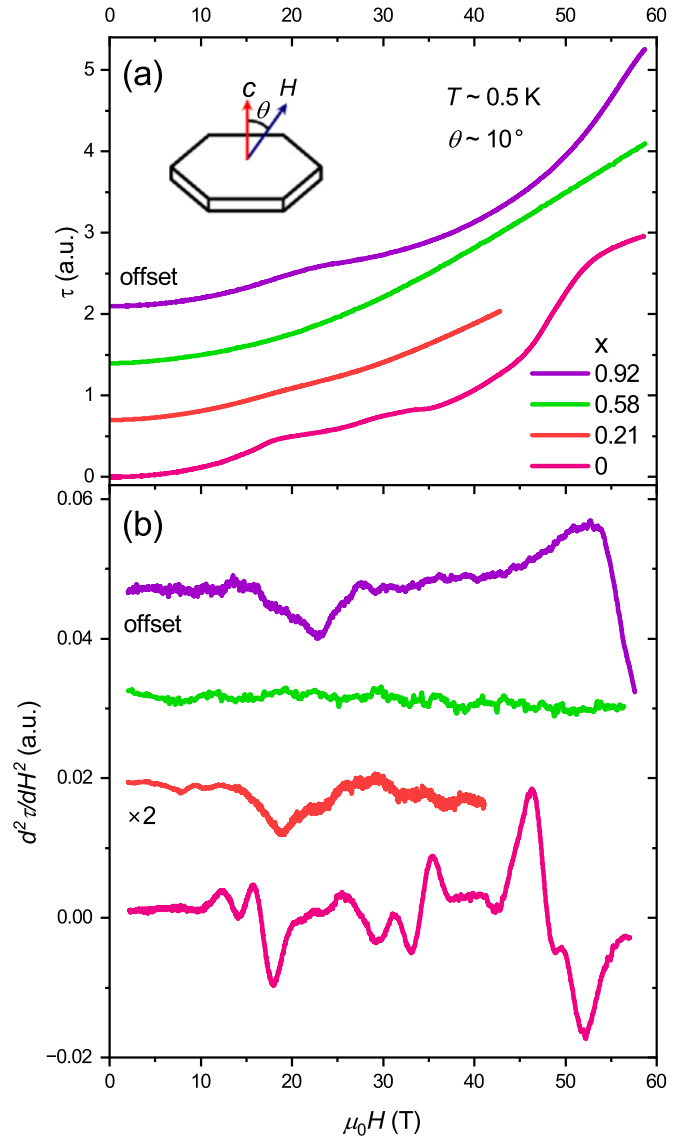


FIG. 4. Magnetic torque measurements and magnetic oscillations. (a) The raw data of magnetic torque for different Cl-doping levels, measured at 0.5 K up to 59 T with $\theta \sim 10^\circ$, where θ is the angle between H and the c axis. (b) The second derivative of torque, $d^2\tau/dH^2$, versus magnetic field. “ $\times 2$ ” represents that the data are multiplied by 2 for clarity.

data up to 59 T at 0.5 K with the field applied 10° away from the c axis ($\theta \sim 10^\circ$) for different Cl-doping levels is shown in Fig. 4(a). Some finer features, in addition to the quadratic paramagnetic torque background, are discernible in the raw data. To emphasize these features, Fig. 4(b) shows the second derivative of the torque with respect to field, $d^2\tau/dH^2$, which enhances field-dependent anomalies in the torque response and provides a sensitive probe of plateau-related features. The first prominent feature is the dip induced by the 1/9 plateau around 20 T in the $x = 0, 0.21$, and 0.92 samples, consistent with the magnetization observations shown in Fig. 3(a). In the $x = 0$ sample, following the 1/9 magnetization plateau, a series of magnetic oscillations appear at higher fields (20 – 50 T), accompanied by a deep minimum around 52 T, which

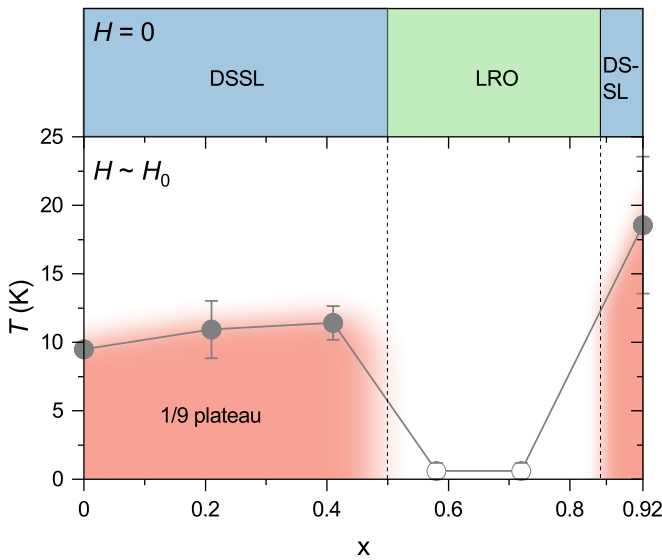


FIG. 5. Comparison between zero-field ground state and the 1/9 magnetization plateau near $H = H_0$ in YCOB-Cl. The top panel shows the zero-field ground state in different Cl-doping level samples separated by solid lines. Bottom panel displays the magnetic phase at $H \sim H_0$, and the red regions indicate where the 1/9 magnetization plateau has been observed. The solid gray dots are the fitted T_p via Eq. (1) [Fig. 3(c)], representing the characteristic temperature scale of the plateau response. The hollow gray dots indicate the lowest measured temperature used as an upper bound for any unresolved plateau response in the ordered phases.

is the signature of the 1/3 magnetization plateau. The details of these magnetic oscillations will not be discussed here, as similar observations and their proposed origins are provided in Ref. [15], where they are explained as a consequence of the spinon Fermi surface. In Fig. 4(b), clear oscillations are only observed in the $x = 0$ sample. Although some small oscillations are present in the range [25, 40] T in the $x = 0.21$ sample, they are too weak to be conclusively identified. For higher Cl-doping levels, magnetic oscillations are either completely absent or the noise is too large for a reliable analysis, indicating that the $x = 0$ case is particularly special and unconventional.

V. DISCUSSION

Finally, we summarize our observations of magnetic properties for different Cl-doping levels in Fig. 5. The top panel presents the ground states near zero field as discussed in Sec. II, and supported by previous studies [21, 30]. We note that, according to Ref. [21], even samples with the same x value can exhibit different ground states depending on the growth conditions. Therefore, the ground states labeled here apply only to our specific samples. The bottom panel of Fig. 5 tracks the evolution of the 1/9 magnetization plateau at high fields around $H \sim H_0$. The plateau regions are marked in red, and the fitted characteristic temperature scale (T_p) values are shown as gray dots. For compositions lacking a plateau ($x = 0.58$ and 0.72), T_p is set at the lowest measured temperature, indicated by hollow gray dots. Comparing both panels reveals that a DSSL ground state is generally accompanied by the 1/9

plateau, whereas the plateau is absent in ordered states. The above observation indicates that the ground state and the 1/9 plateau are closely related to each other.

At zero field, an ideal QSL state in a uniform kagome lattice is fragile and tends toward AFM ordering even with small DM interaction [31, 32], as seen in $\text{YCu}_3(\text{OH})_6\text{Cl}_3$ [33]. More generally, disorder does not have a universal effect on QSL excitations. For example, in Kitaev systems, bond randomness and site dilution can strongly modify fractionalized excitations and suppress characteristic gapless or topological responses [34, 35]. In contrast, random-bond kagome systems can host disorder-stabilized spin-liquid-like regimes that remain robust even in the presence of sizable DM interactions [36–38]. This latter scenario may be relevant to YCOB-Cl. As discussed in Ref. [21], disorder and randomness do not simply obscure the spin-liquid ground state, but may play an essential role in its formation. At the same time, disorder may also generate random-singlet-like contributions coexisting with the QSL-like state, as has been observed in strongly disordered Kitaev materials [39], which needs further studies to clarify. Here we showed that the 1/9 magnetization plateau is correlated with the zero-field ground state, suggesting that the microscopic ingredients responsible for the DSSL regime are also relevant to the high-field plateau. This correlation may also reflect the fact that in the LRO samples, an ordered phase is more stable and suppresses the plateau response. Meanwhile, numerical studies of random-bond kagome Heisenberg models generally find that sufficiently strong bond disorder tends to smear magnetization-plateau features [36, 37]. The observation of clear plateau signatures in the DSSL samples therefore requires a more material-specific description, because the exchange randomness in YCOB-Cl is tied to distinct local structural motifs and coexists with additional interactions such as DM terms, rather than being captured by a single uncorrelated disorder parameter.

The exact mechanism by which the disorder contributes to plateau formation is still unclear. Empirically, the $x = 0$ data favor the gapless phenomenology described by Eq. (1) within our accessible temperature window, whereas for the Cl-doped samples ($x = 0.21$, 0.41 , and 0.92) the activated form in Eq. (3) provides a slightly better description, yielding an effective activation scale of a few kelvin (Table II). While these fits do not by themselves establish a definitive excitation gap, they indicate a systematic suppression of low-energy spectral weight upon Cl substitution. Consistently, the torque oscillations above the 1/9 plateau are resolved only for $x = 0$ and are not observed in the Cl-doped samples, indicating that the oscillatory state requires more restrictive conditions than the plateau itself and is strongly suppressed by chemical substitution. Further measurements at lower temperatures and more detailed theoretical modeling tailored to the exchange randomness in YCOB-Cl will be important for clarifying the excitation spectrum and the role of disorder in the formation of the 1/9 plateau.

VI. CONCLUSION

By studying the magnetic properties of YCOB-Cl across a broad range of chlorine doping, we mapped the evolution of the 1/9 magnetization plateau over the studied doping series.

Clear plateau signatures are observed for $0 \leq x \leq 0.41$ and $x = 0.92$, while they are absent in the LRO compositions, revealing a close connection between the high-field plateau and the zero-field ground state. The temperature dependence of the 1/9 plateau evolves with Cl substitution: the $x = 0$ data favor a gapless spinon phenomenology, whereas the Cl-doped samples are more consistent with an activated model, suggesting a possible gap scale of order 4 K. This trend is further supported by torque measurements, where magnetic oscillations above the 1/9 plateau are resolved only in the $x = 0$ sample and are absent in the Cl-doped samples, consistent with the suppression of low-energy spectral weight upon Cl substitution. YCOB-Cl therefore provides a valuable platform for exploring the interplay among disorder, quantum spin liquids, unconventional magnetization plateaus, and exotic magnetic oscillations.

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DATA AVAILABILITY

The data that support the findings of this article are publicly available in the Open Science Framework repository [40].

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