

Cascade of magnetic phase transitions and large topological Hall effect in the noncentrosymmetric antiferromagnet $\text{Eu}_2\text{Pd}_3\text{Bi}_4$

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The interplay between symmetry breaking, spin-orbit coupling, and magnetic frustration in noncentrosymmetric antiferromagnets has emerged as a fertile ground for discovering intertwined topological and quantum phenomena. Here, we report a cascade of magnetic phase transitions and a large topological Hall response in the newly discovered noncentrosymmetric antiferromagnetic (AFM) material $\text{Eu}_2\text{Pd}_3\text{Bi}_4$ with a Néel temperature $T_N = 7.6$ K. Under magnetic fields (H) parallel to the c axis, two successive phase transitions at critical fields H_1 and H_2 are observed in magnetization at temperatures below T_N , which are attributed to the occurrences of sequential field-induced spin states. A pronounced topological Hall effect signal emerges exclusively within an intermediate field window $H_1 < H < H_2$, signifying the formation of topological spin textures. The field-temperature phase diagram mapped via specific heat and magnetoelectric transport measurements incorporates five phase regimes: The paramagnetic state, a high-field polarized state, and three AFM states with distinct spin configurations. Our results identify $\text{Eu}_2\text{Pd}_3\text{Bi}_4$ as a good candidate for scrutinizing sophisticated interplays between magnetic structure and nontrivial band topology.

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I. INTRODUCTION

The exploration of spin textures has emerged as a central research direction in contemporary condensed matter physics. In particular, studies of magnetic field-induced evolution of spin states bring crucial insights into critical phenomena, spin dynamics, and novel quantum states [1–6]. Recent advances in noncentrosymmetric antiferromagnetic (AFM) systems have unveiled rich emergent phenomena arising from the interplay between spin-orbit coupling, broken inversion symmetry, and complex magnetic order [7–10]. Unlike conventional centrosymmetric magnets, the absence of inversion symmetry in these materials introduces antisymmetric Dzyaloshinskii-Moriya (DM) interactions [11,12], which stabilize nontrivial spin textures such as chiral domain walls [13,14] and magnetic skyrmions [15–17]. The energy competition between these spin states results in a complex magnetic phase diagram with respect to temperature, magnetic field, and pressure. In some cases, a myriad of magnetic phase transitions can emanate

from these competing energy scales under varying external stimuli, e.g., temperature (T) and magnetic fields (H), serving as a crucial pathway for manipulating spin states and establishing their correlation with electronic transport properties.

In magnetic systems, topologically nontrivial spin textures give rise to novel electromagnetic phenomena such as extreme magnetoresistance (MR) [18], the axion insulator state [19,20], the quantum anomalous Hall effect [21,22], and the topological Hall effect (THE) [17,23–26]. The THE has been proposed to emerge in the presence of noncoplanar spin configurations, making it a potential hallmark of AFM materials hosting highly noncollinear and noncoplanar spin structures. The origin of THE can be understood through the real-space integral $\int (d^2\mathbf{r}/V) \mathbf{m} \cdot \partial_x \mathbf{m} \times \partial_y \mathbf{m}$, which arises from the Berry phase acquired by electrons traversing a spatially varying magnetic texture $\mathbf{m}(\mathbf{r})$ with nonzero Berry curvature [27]. In basic form, the scalar spin chirality, defined as $\chi_{ijk} = \mathbf{S}_i \cdot (\mathbf{S}_j \times \mathbf{S}_k)$ for three neighboring spins, breaks the time-reversal symmetry and generates the real-space Berry curvature [28,29]. This establishes THE as a reliable probe for detecting the existence of topological spin states (e.g., skyrmions) in diverse materials [30]. Specifically, the presence of topological spin texture acts like a fictitious magnetic field that drives the transverse electron motion, thereby inducing the topological Hall response [23,31,32]. For instance, in bulk antiferromagnets, field-driven transitions between collinear and noncoplanar spin states correlate with changes in THE signals [33–35]. Similarly, in thin-film heterostructures,

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the interfacial DM interaction enables stabilization of Néel-type skyrmions, whose field-controlled motion produces THE signatures [36,37]. These discoveries bridge antiferromagnetic spintronics with topology physics, providing routes toward low-power electronic devices. Despite extensive investigation on individual aspects of THE or magnetic transitions, the synergistic relationship between cascade magnetic transitions and THE in noncentrosymmetric AFMs remains poorly understood.

In this work, we report the discovery of a noncentrosymmetric antiferromagnet $\text{Eu}_2\text{Pd}_3\text{Bi}_4$ with the AFM transition temperature $T_N = 7.6$ K. Through systematic investigations of the magnetoelectric transport properties, we reveal the intricate interplay between topological transport phenomena and magnetic ordering states. Based on the magnetization and torque measurements, a cascade of magnetic transitions is observed under a magnetic field parallel to the c axis ($H \parallel c$) due to the reorientation of spins induced by the magnetic field, while there is no obvious signal of magnetic transition with magnetic field perpendicular to the c axis ($H \perp c$). Meanwhile, electrical transport measurements reveal non-monotonic behavior in both longitudinal and Hall resistivities. A prominent topological Hall response is detected on the Hall resistivity, whose activation and disappearance thresholds coincide with the two metamagnetic transitions. The presence of THE indicates the formation of nontrivial topological spin states in the regime. A comprehensive magnetic phase diagram, consisting of a paramagnetic (PM) state, a high-field polarized state, and three distinct field-induced AFM states, has been constructed based upon the magnetic torque, transport, and specific heat data with $H \parallel c$. Our findings provide a rich platform for exploring novel spin textures and emergent electromagnetic phenomena.

II. EXPERIMENTAL METHODS

High-quality single crystals of $\text{Eu}_2\text{Pd}_3\text{Bi}_4$ were successfully grown by a melt method. First, Eu (99.5%) flakes, Pd powder (99.9%), and Bi powder (99.999%) were mixed with the molar ratio of 2:3:4 in a glove box filled with argon gas. Then, the mixture was loaded into an alumina crucible and sealed in a double-walled quartz ampoule. The above ampoule was heated to 1000 °C in 5 h, kept at 1000 °C for 10 h, and then slowly cooled down to 600 °C in 3 days, followed by a quenching operation. Sheetlike single crystals with typical dimensions of $0.6 \times 0.5 \times 0.05$ mm³ were obtained by mechanical exfoliation. The specific crystal structure was determined through a four-circle single crystal x-ray diffraction (SC-XRD) measurements. The structure data were collected from SC-XRD at 300 K with Cu K α radiation (Rigaku XtaLAB PRO 007HF) in Core Facility Center for Life Sciences, USTC; the data were further processed and reduced using CrysAlisPro and the structure was solved and refined using Olex-2 with the ShelXT and ShelXL packages.

Magnetic susceptibility and magnetic torque measurements were performed at the Chinese High Magnetic Field Laboratory (CHMFL) in Hefei in a Quantum Design Physical Property Measurement System (PPMS-14T) and a 35 T water-cooled Bitter magnet, respectively. The magnetic susceptibility and magnetization data were measured in different

directions of the same sample. The torque measurement studies were conducted based on magnetic torque data probed using an SCL piezoresistive self-sensing cantilever, as shown in Fig. S1 in the Supplemental Material [38]. The magnetic torque can be defined as the vector product: $\tau_q = \mu_0 M \times H$; its amplitude is thus $\tau_q = \mu_0 M_{\perp} H$. Here, M is the sample magnetization vector and $M_{\perp} = \tau_q / \mu_0 M$ is the transverse magnetization (the component of M perpendicular to H). During the measurements, the piezoresistive cantilever was mounted on a fixed sample holder that was attached to a straight probe. H was applied perpendicular and parallel to the c axis, respectively.

Longitudinal resistivity, Hall measurements, and specific heat measurements were conducted in a Quantum Design Physical Property Measurement System (DynaCool-14 T). All of the in-plane electrical transport data were measured in a standard Hall-bar configuration. For single crystal-specific heat measurement, Apiezon-N vacuum grease was employed to fix crystals to the sapphire sample platform. The specific heat contribution from the sample holder platform and grease was determined before mounting the sample and subtracted from the total heat capacity. The residual resistivity and Hall conductivity of different samples vary slightly. Besides certain quantitative differences, the magnetoelectric transport properties were consistent across multiple crystals and batches.

III. RESULTS AND DISCUSSION

The crystal structure of $\text{Eu}_2\text{Pd}_3\text{Bi}_4$ is shown in Fig. 1(a), which crystallizes in a noncentrosymmetric orthorhombic lattice with space group $Pba2$. In the structure, Pd atoms are located at two different sites, forming tetrahedral and tetrapyramidal configurations with the surrounding Bi atoms, respectively. The specific structure information solved from the four-circle SC-XRD is shown in Table S1 in the Supplemental Material [38]. A series of sharp (00 l) diffraction peaks [Fig. 1(b)] and the sharp spots reconstructed from the SC-XRD (Fig. S2 in the Supplemental Material [38]) suggest the high quality of the single crystal. Figure 1(c) displays the temperature dependence of magnetic susceptibility χ under field $\mu_0 H = 1$ T applied perpendicular and parallel to the c axis, respectively. The long-range AFM order is clearly observed at the Néel temperature $T_N = 7.6$ K. Above T_N , the susceptibility follows the Curie-Weiss law with the effective magnetic moments $\mu_{\text{eff}} = 7.78(8)$ and $8.69(5) \mu_B$ per Eu^{2+} for the field applied perpendicular and parallel to the c axis, respectively. These values are close to the effective magnetic moment $\mu_{\text{eff}} = 7.94 \mu_B$ of the high-spin state of Eu^{2+} with $S = 7/2$. The Curie-Weiss temperatures θ_{CW} are both -23 K for the field applied in and out of plane, showing a dominant AFM interaction in $\text{Eu}_2\text{Pd}_3\text{Bi}_4$.

To investigate the magnetic field-dependent evolution of the Néel temperature T_N , we have measured the temperature dependence of the magnetic susceptibility under various magnetic fields applied perpendicular and parallel to the c axis, respectively, as shown in Fig. S3 in the Supplemental Material [38]. In both cases, the T_N exhibits systematic suppression with increasing magnetic field. Notably, an additional transition induced by the field is observed in the middle range of the magnetic field for $H \parallel c$, attributed to the

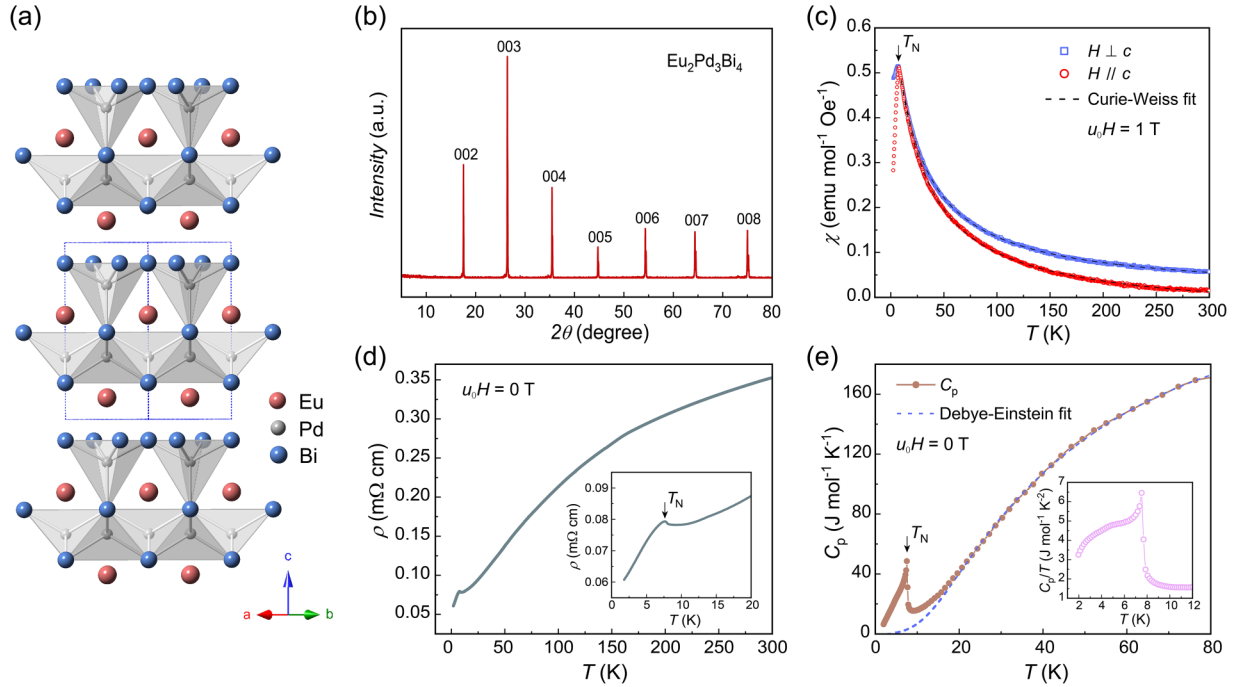


FIG. 1. Structure and antiferromagnetic order of $\text{Eu}_2\text{Pd}_3\text{Bi}_4$ single crystal. (a) Schematic crystal structure of $\text{Eu}_2\text{Pd}_3\text{Bi}_4$. Blue dashed lines denote the crystalline unit cell. (b) Single-crystal (SC)-XRD patterns for $\text{Eu}_2\text{Pd}_3\text{Bi}_4$; (00 l) series of diffraction peaks are clearly observed. (c) Magnetic susceptibility χ for field $\mu_0 H = 1$ T applied perpendicular (blue boxes) and parallel (red circles) to the c axis for $\text{Eu}_2\text{Pd}_3\text{Bi}_4$ single crystal, respectively. Black dashed lines denote Curie-Weiss fits. (d) Temperature dependence of in-plane resistivity ρ measured in $\text{Eu}_2\text{Pd}_3\text{Bi}_4$ single crystal. Inset shows expanded views of the antiferromagnetic transition. (e) Temperature dependence of specific heat C_p at zero field of $\text{Eu}_2\text{Pd}_3\text{Bi}_4$. The blue dashed line denotes Debye-Einstein fit. Inset displays the temperature dependence of C_p/T at low temperatures. In panels (c)–(e), antiferromagnetic transition temperature T_N is clearly identified and consistent with each other.

reorientation of the spin in different magnetic fields. In addition, the AFM transition is further identified by the temperature dependence of longitudinal resistivity [Fig. 1(d)] and specific heat [Fig. 1(e)] at zero field. The resistivity ρ exhibits a metallic behavior below 300 K. The T_N decreases with the increase of field applied out of plane until it is suppressed to 2 K with $\mu_0 H = 17$ T (Fig. S4 in the Supplemental Material [38]). There is no significant anisotropic behavior in this system through the measurement of the in-plane resistivity $\rho(T)$ with H parallel and perpendicular to the c axis and the out-of-plane resistivity ρ_c (Fig. S5 in the Supplemental Material [38]). A sharp peak corresponded to the AFM transition is observed in specific heat curve. The phonon contribution is obtained by a combined Debye-Einstein model [39,40],

$$C_p(T) = \gamma_0 T + 9NR\alpha \left(\frac{T}{\theta_D} \right)^3 \int_0^{\theta_D/T} \frac{x^4 e^x dx}{(e^x - 1)^2} + 3NR(1 - \alpha) \left(\frac{\theta_E}{T} \right)^2 \frac{e^{\theta_E/T}}{(e^{\theta_E/T} - 1)^2}, \quad (1)$$

where γ_0 is the specific heat coefficient of the conduction electrons, N is the number of the atoms in the formula unit, θ_D and θ_E are the Debye and Einstein temperatures, respectively, R is the universal gas constant, and α is the contribution ratio of the two components. This analysis yields characteristic temperatures of $\theta_D = 120$ K and $\theta_E = 234$ K, with the electronic contribution proving negligible during high temperature regime fitting. It is noted that although the specific heat was fitted using percentage weighting, the resulting parameter

$\alpha = 0.67$ is very close to the integer weighting of 6/9. Moreover, a fit incorporating two Einstein temperature terms yielded no significant change in the result (Fig. S6 in the Supplemental Material [38]). For $H \parallel c$, the T_N progressively decreases with increasing magnetic field (Fig. S7 in the Supplemental Material [38]), consistent with the result of resistivity and susceptibility. Similarly, a significant transition induced via magnetic field is discovered from the specific heat at the field range of 5–8 T [Fig. S7(c) in the Supplemental Material [38]], which indicates the emergence of a metastable state within the range through the manipulation of spin alignment by magnetic field. We also analyzed the entropy release at T_N followed as $S_{\text{mag}} = \int_0^T C_{\text{mag}}(T)/T dT$. The saturation entropy approaches the theoretical value $R \ln(2S + 1)$ for Eu^{2+} ($S = 7/2$) at 0 T (Fig. S8 in the Supplemental Material [38]).

Figures 2(a) and 2(b) show magnetization results as a function of field at different temperatures for magnetic field applied parallel and perpendicular to the c axis, respectively. There are two prominent successive magnetic transitions of the magnetization curves measured at low temperatures for $H \parallel c$. For example, at 2 K, magnetization increases with the increasing field. Two steps occur at 4.8 and 8.5 T, respectively, and then it increases linearly with the field. A slightly hysteresis of magnetization at the transition (Fig. S9 in the Supplemental Material [38]) is detected with the measurement of the rising and falling field at low temperature, indicating the clearly first-order nature for each transition. Conversely, there is no anomaly in magnetization for $H \perp c$ [Fig. 2(b)].

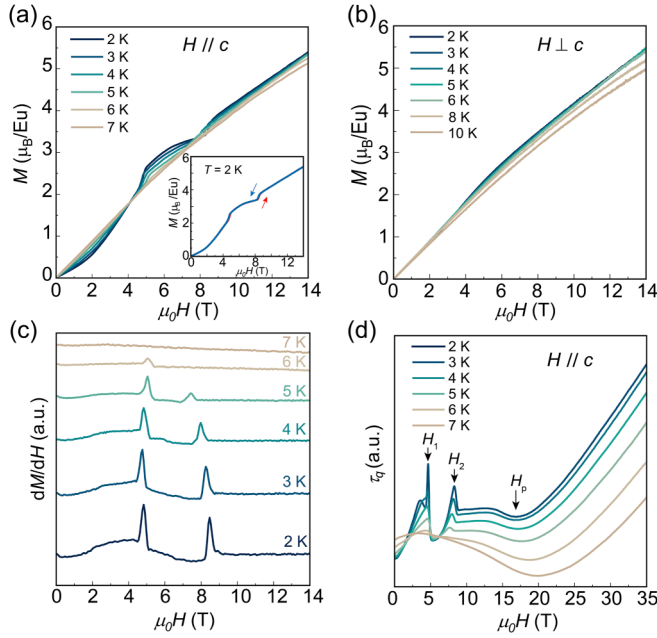


FIG. 2. Magnetic properties of $\text{Eu}_2\text{Pd}_3\text{Bi}_4$. (a), (b) Magnetization as a function of magnetic fields at various temperatures under magnetic field applied parallel (a) and perpendicular (b) to the c axis, respectively. Inset of panel (a) shows the magnetization characteristics at 2 K, where the red and blue lines represent the rising and falling field measurement behaviors, respectively. (c) Derivative of the magnetization in panel (a) vs magnetic field. Data are offset vertically for clarity. (d) Magnetic field dependence of torque at various temperatures under magnetic field applied parallel to the c axis. The arrows and labels indicate the critical field of different magnetic transition below 35 T.

The magnetization does not saturate at the maximum field of 14 T with the magnetic moment of $5.5 \mu_B$ per Eu^{2+} , which is less than the estimated moment of $M_s = g\mu_B S = 7 \mu_B$ per Eu^{2+} . To explicitly elucidate the magnetization process for $H \parallel c$, we plot the differential of magnetization (dM/dH) versus magnetic field at different temperatures in Fig. 2(c). At low temperature, the differential curves show two sharp peaks, representing the lower- and upper-bound fields of the magnetization in intermediate state regime. As the temperature increases, although the lower-bound field remains almost unchanged, the upper-bound field is reduced rapidly and merges together at close to 6 K, and then the transition disappears as temperature approaches T_N . Meanwhile, magnetic torque (τ_q-H) of $\text{Eu}_2\text{Pd}_3\text{Bi}_4$ is measured below 35 T to further identify the characteristics of magnetization. The torque curves for $H \parallel c$ exhibit two clear peaks at critical fields H_1 and H_2 due to two successive magnetic transitions [Fig. 2(d)], and no transition is observed for $H \perp c$, [Fig. S10(a) in the Supplemental Material [38]], agreeing well with the results of magnetization. With the field increasing, the magnetic structure crosses over to the FIP state at critical field H_p , as shown in Fig. 2(d) and Fig. S10(b) in the Supplemental Material [38]. The magnetoresistance with magnetic field along the c axis exhibits a sign change behavior at the critical field H_p , indicating a transformation of the system to an FIP state, which is consistent with the result observed in magnetic torque [Fig. S10(c) in the Supplemental Material [38]].

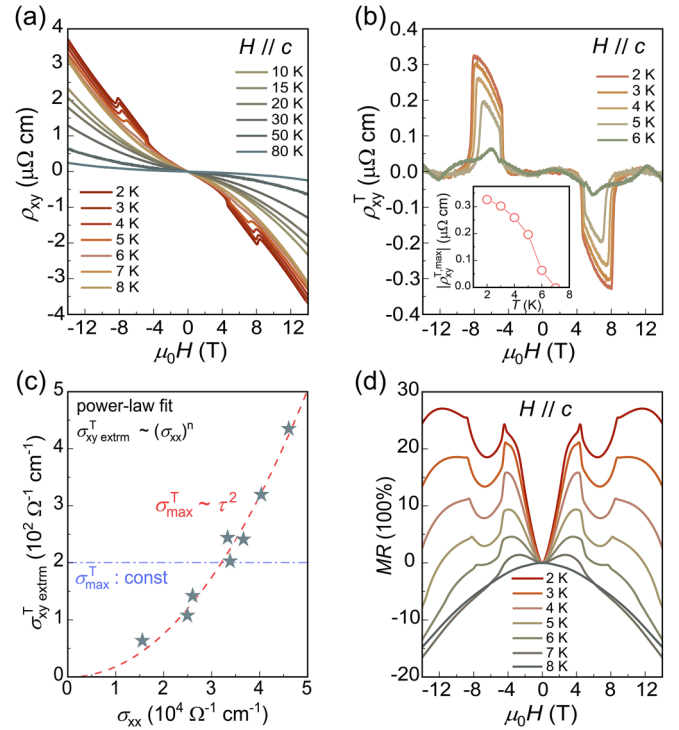


FIG. 3. Topological Hall effect and magnetoresistance of $\text{Eu}_2\text{Pd}_3\text{Bi}_4$. (a), (b) Magnetic field dependence of Hall resistivity ρ_{xy} and topological Hall resistivity ρ_{xy}^T at various temperatures under magnetic field applied parallel to the c axis. Inset of panel (b) shows temperature dependence of the maximum values of ρ_{xy}^T below T_N . (c) Scaling plot of extreme value of $\sigma_{xy}^T(H, T)$ as a function of $\sigma_{xx}^T(H, T)$. The red dashed line represents the fit to the quadratic dependence, while the blue dash-dotted line corresponds to the τ -independent constant term. (d) Magnetic field dependence of MR at various temperatures with magnetic field parallel to the c axis. The measured magnetic field ranges from -14 to 14 T.

To study the electrical transport behavior across distinct magnetic phase regions, we have conducted measurements of Hall effect and MR in $\text{Eu}_2\text{Pd}_3\text{Bi}_4$ single crystals, as shown in Fig. 3. The Hall resistivity ρ_{xy} displays a nonlinear field dependence behavior. The transverse resistivity ρ_{xy} is generally made up of three components: $\rho_{xy} = R_0 B + R_S M + \rho_{xy}^T$, where the first and second terms denote the ordinary and anomalous Hall resistivities, and the third term represents the topological component. At low temperature, a significant enhancement of ρ_{xy} is apparent in the region between two stepwise changes of magnetization, suggesting the presence of THE. In the system, the ordinary Hall resistivity ρ_{xy}^N could be successfully analyzed using a two-band model [41,42] incorporating both electron- and hole-type carriers [Fig. S11(a) in the Supplemental Material [38]]:

$$\rho_{xy} = \frac{1}{e} \frac{(n_h \mu_h^2 + n_e \mu_e^2) \mu_0 H + (n_h - n_e) \mu_h^2 \mu_e^2 (\mu_0 H)^3}{(n_h \mu_h + n_e \mu_e)^2 + (n_h - n_e)^2 \mu_h^2 \mu_e^2 (\mu_0 H)^2}, \quad (2)$$

where n_h and n_e are the carrier densities of holes and electrons ($n_e > 0$), respectively. μ_h and μ_e are the hole and electron mobilities, respectively. We obtain the concentration of electron ($n_e \sim 10^{21} \text{ cm}^{-3}$) and hole ($n_h \sim 10^{18} \text{ cm}^{-3}$) carriers [Fig. S11(b) in the Supplemental Material [38]],

and the Hall mobility [Fig. S11(c) in the Supplemental Material] by the two-band model fitting, revealing electron-dominated charge transport behavior. The excellent fitting quality across all measured temperatures enables reliable extraction of the topological component ρ_{xy}^T from ρ_{xy} , as shown in Fig. 3(b). The magnitude of the THE at the lowest temperature is as large as $0.33 \mu\Omega \text{ cm}$, which is comparable to or even one order of magnitude larger than that in other skyrmion-hosting materials such as FeGe thin film [43] and high-pressure MnSi bulk [32,44]. A shorter spin modulation wavelength ($\sim 6.4 \text{ nm}$) is estimated (see the Supplemental Material [38]) [45], in contrast to the relatively large size of skyrmions (10–100 nm) in typical noncentrosymmetric magnets [46].

The temperature-dependent evolution shows continuous suppression of the σ_{xy}^T and ρ_{xy}^T peak amplitudes with increasing temperature (Fig. S12 in the Supplemental Material [38]), which indicates that this response is affected by the strength of the molecular field, consistent with the spin chirality model for the THE [17]. In conventional scenarios, the THE exhibits distinct dependencies on the scattering time τ , governed by its underlying mechanism. For the intrinsic mechanism arising from the momentum-space Berry curvature, the anomalous Hall component shows τ -independent behavior [47,48]. Conversely, in the case of the THE induced by topological spin textures such as magnetic skyrmions, the topological hall conductivity σ_{xy}^T is expected to show τ^2 dependence. This characteristic scaling originates from the proportionality between the fictitious magnetic flux in real space and the density of topological spin textures within a given area [27,49]. In cases where the anomalous Hall effect is caused by extrinsic contributions such as skew scattering, the anomalous Hall conductivity is expected to exhibit a linear dependence on the scattering time. To further explore the generation mechanism of the THE, we have conducted Hall effect measurements on eight crystals of $\text{Eu}_2\text{Pd}_3\text{Bi}_4$ and performed scaling analysis on the data at lowest measurement temperatures (2 K). As shown in Fig. 3(c), the topological Hall conductivity σ_{xy}^T exhibits a good quadratic dependence on the scattering time τ , implying a possibility of THE induced by the nontrivial spin texture in this system. Meanwhile, our Hall data reveal a typical multi-band behavior except for anomalies observed between 5 and 9 T. At low temperatures, after subtracting the ordinary Hall contribution with two-band fitting, the Hall resistivity shows no clear scaling relationship with magnetization (Fig. S13 in the Supplemental Material [38]). We therefore tend to believe that these anomalies likely originate not from the conventional anomalous Hall effect (which scales with magnetization), but rather from topological Hall components arising from unique spin textures in the material. In addition, in some certain magnets without static spin chirality, a nonzero internal magnetic field can emerge dynamically through the preferential excitation of chiral fluctuations with a given handedness, possibly leading to the generation of THE [50]. Generally, the magnitude of fluctuation-driven THE is proportional to both the applied field and temperature [38,50], a trend distinct from the behavior observed in our system. These observations suggest that the formation of nontrivial spin textures driven by the

bulk DM interaction leads to the emergence of the THE under magnetic field.

Furthermore, the MR curves present the characteristics of two successive transitions below T_N for $H \parallel c$ [Fig. 3(d)]. The continuous evolution between each state is marked by the maximum of sharp peaks on the MR, which coincides with the two metamagnetic transitions. When the temperature is below T_N , the positive MR behavior emerges at low fields and transforms into a characteristic U -shaped dip between the two critical fields, which is possible associated with the nontrivial spin textures [51]. As the magnetic field further increases, the negative MR response persists until it becomes positive in the spin-polarized state, without reaching saturation even under high fields [Fig. S10(c) in the Supplemental Material [38]]. Specifically, in $\text{Eu}_2\text{Pd}_3\text{Bi}_4$, metamagnetic transitions have been observed under a magnetic field applied along the c axis, accompanied by nonmonotonic variations of longitudinal and transverse transport properties. These pronounced transport anomalies demonstrate remarkable sensitivity to spin configurations, providing compelling evidence for strong exchange coupling between conduction electrons and the localized Eu^{2+} moments.

Based on the magnetic torque, transport and specific heat data, we constructed a magnetic phase diagram with $H \parallel c$ for $\text{Eu}_2\text{Pd}_3\text{Bi}_4$, as shown in Fig. 4(a). It consists of five distinct regimes. Under a sufficiently large magnetic field, the spin is polarized along the direction of the magnetic field to form an FIP state in the blue regime, the phase boundary of which is determined by the critical fields H_p from the τ_q-H curves with different temperatures in Fig. 2(d). The phase boundary between the long-range order and PM state is determined by extracting the peaks from the resistivity (Fig. S4 in the Supplemental Material [38]) and specific heat (Fig. S7 in the Supplemental Material [38]), which are mutually consistent. The transition temperature T_N is gradually suppressed with increasing magnetic field. At the low temperature, the system undergoes two consecutive metamagnetic transitions, demarcating three distinct phase regimes. The AFM-I regime corresponds to the magnetic ground state, whose upper boundary is established through critical fields H_1 defined by peak analysis of both τ_q-H and $M-H$ curves. The upper phase boundary remains almost flat until 7 K, where it merges into the outer boundary. The boundary between the AFM-II and AFM-III regimes can be identified via critical fields H_2 from τ_q-H curves, $M-H$ isotherms, specific heat data, and susceptibility $M-T$ results, demonstrating remarkable consistency across experimental methods. It is worth mentioning that the upper phase boundary of AFM-II regime decreases with the temperature increasing and converges with the lower boundary at 6 K, and the upper-bound field of AFM-III regime coincides with the phase boundary separating long-range order from the paramagnetic state.

By correlating the magnetic phase diagram with the spatial distribution of the topological Hall resistivity ρ_{xy}^T , we observe that the pronounced topological response predominantly coincides with the temperature and field range of the AFM-II regime, as shown in Fig. 4(b). The enhanced topological Hall signal appearing exclusively in the AFM-II regime suggests

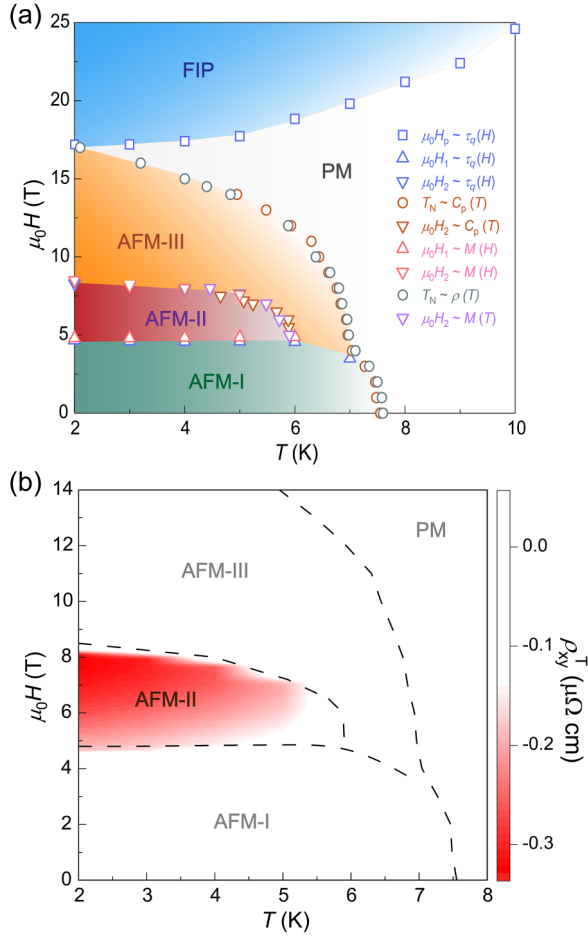


FIG. 4. Magnetic phase diagram and topological Hall phase of $\text{Eu}_2\text{Pd}_3\text{Bi}_4$. (a) Phase diagram with field applied parallel to the c axis. The lower green AFM-I zone represents the AFM ground state and the central carmine (AFM-II) and orange (AFM-III) areas represent two AFM states with magnetic field-induced different spin configurations. The blue zone is the field-induced polarized (FIP) state. PM denotes the paramagnetic state when the temperature is above T_N . Blue boxes represent the polarized fields (H_p) obtained from the τ_q-H curves. Brown and green circles denote the Néel temperatures extracted from the specific heat and resistivity data. The up and down triangles represent the two critical fields (H_1 and H_2) of magnetic transition obtained from the τ_q-H curves (blue), $M-H$ isotherms (pink), the specific heat (brown), and magnetic susceptibility data (purple), respectively. (b) Contour map of topological Hall resistivity for magnetic field applied parallel to the c axis. The red zone represents the response of THE. The black dashed lines denote the demarcation lines between distinct phases in panel (a).

that in $\text{Eu}_2\text{Pd}_3\text{Bi}_4$ the application of magnetic field induces topological phase transitions associated with spin texture re-configuration, likely originating from a nonzero average spin chirality akin to skyrmion lattice systems [17,52]. In such systems, spin-polarized electrons traversing the skyrmion texture acquire a Berry phase by adiabatically aligning their spins to the local magnetization direction, thereby generating the THE [37]. The distinct emergent electrodynamic responses in

AFM-II regime, attributed to its nontrivial topological spin arrangements, starkly contrast with those of adjacent magnetic phases. Considering field-induced nontrivial spin textures, spin state variability, and inherent structural asymmetry, it is challenging to build spin models for different magnetic states. To precisely determine the magnetic structures of $\text{Eu}_2\text{Pd}_3\text{Bi}_4$ under various magnetic fields, single crystal or powder neutron diffraction may be further required, which is an effective method for probing atomic-scale spin correlations.

IV. CONCLUSION

Through comprehensive magnetoelectric transport and specific heat measurements on $\text{Eu}_2\text{Pd}_3\text{Bi}_4$, a magnetic phase diagram, consisting of a paramagnetic state, a high-field polarized state, and three AFM states with different spin textures, has been constructed under magnetic field applied along the c axis. Remarkably, within the boundaries of the AFM-II regime, we detect a large THE with the magnitude of $0.33 \mu\Omega \text{ cm}$, comparable to large THE in skyrmion materials. Strikingly, the activation and disappearance thresholds of THE coincide with the two metamagnetic transitions, suggesting that intermediate field phases stabilize metastable topological spin textures that manifest enhanced THE responses. Our results demonstrate that field-driven cascade transitions mediate abrupt changes in THE signatures, directly reflecting the evolution of topological spin phases. The discovery of the noncentrosymmetric antiferromagnet $\text{Eu}_2\text{Pd}_3\text{Bi}_4$ undoubtedly provides an exceptional platform for exploring novel spin textures, enabled by its inherent structural asymmetry and competing magnetic interactions. These findings not only advance fundamental understanding of correlated topological phenomena in noncentrosymmetric magnets but also provide design principles for AFM-based topological spintronic devices.

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DATA AVAILABILITY

The data that support the findings of this article are openly available [53].

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