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# Current-driven Dynamics of Magnetic Skyrmion Bunches

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Since the discovery of topological spin textures called magnetic skyrmions, much interest has been focused towards these vortex-like textures [1,2] for use as storage bits for future computing applications [3]. To realize this goal, much progress has been made using an electrical current to drive skyrmion motion. While several studies have reported successful current-induced translation of individual skyrmions, only recently have researches begun studying the collective dynamics of multiple skyrmions aggregated into a group [4].

Here we report the current-driven dynamics of magnetic skyrmion bunches within the chiral magnet $Co_{10}Zn_{10}$ measured using defocussed Lorentz transmission electron microscopy. The skyrmions exist within a metastable state at room temperature with no applied external magnetic field. First, using a 1 s long electrical current pulse with a current density of $j = 3.8 \times 10^5 \mathrm{A/cm^2}$, we drive a four-skyrmion bunch in two directions, revealing a center-of-mass (CoM) trajectory that is reversible, suggesting that pinning sites within the material may act as a natural racetrack for skyrmions. Figure 1 (a-e) shows the group trajectory for 1 s long pulse current of $I = -11$ mA, with each panel representing an individual event. Figure 1 (f-h) shows the current flowing in the opposite direction, with the current increased to $I = +11.5$ mA between (g) and (h), corresponding to a current density of $j = 4.0 \times 10^5$ A/cm$^2$. Finally, we observed the dynamics of a three-skyrmion bunch driven by a 10 µs long current pulse with a current density of $j = 6.9 \times 10^5$ A/cm$^2$. Figure 2 (a) shows the resulting trajectory, with a group velocity on the order of 10 mm/s and a Hall angle ranging between 30° and 90°, as shown in the CoM trajectory of the skyrmion bunch traced with purple circular markers. The starting position of the skyrmion bunch is indicated with a green '+' marker, and the individual skyrmions are traced with red star-shaped markers. Figure 2 (b) shows the handedness of rotation of the skyrmion bunch, accumulated over the pulse currents shown in (a). Out of seven current-pulse events, five resulted in skyrmion rotation in the counter-clockwise (CCW) direction, one resulted in no rotation (Translation) and one resulted in clockwise rotation, suggesting a preferred rotation direction for a positive current ($I = +20$ mA).

These results suggest the existence of an underlying rotation mechanism for skyrmion bunch rotation. If the rotation tends to be unichiral for short current pulses, it may be due to the magnus force intrinsic to electrical current - magnetic moment interaction. This study marks an important step towards understanding this interaction within multi-skyrmion bunches, and begs for further investigation.

References

1. Mühlbauer, S. *et al.*, "Skyrmion Lattice in a Chiral Magnet." Science **323**, 915-19 (2009).

2. Yu, X. *et al.*, "Real-space observation of a two-dimensional skyrmion crystal." Nature **465**, 901-4 (2010).

3. Nagaosa, N. and Tokura, Y., "Topological properties and dynamics of magnetic skyrmions." Nature Nanotechnology **8**, 899-911 (2013).

4. Yu, X. *et al.*, "Motion tracking of 80-nm-size skyrmions upon directional current injections." Science Advances **6**, 25, eaaz9744 (2020).

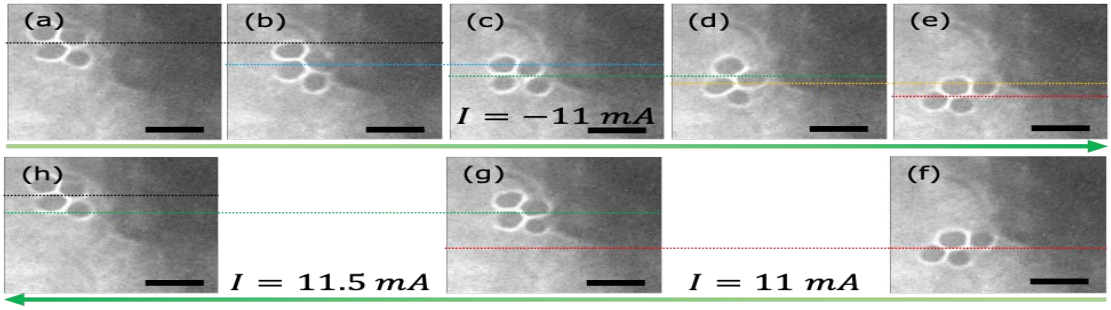


**Figure 1.** Four-skyrmion bunch trajectory driven by 1 s long electrical DC current pulses of amplitude a-e) I = $-11\ mA$, f-g) I = $+11\ mA$, and g-h) I = $+11.5\ mA$, with the current direction indicated by the green arrows. These amplitudes represent the critical current necessary to free the skyrmion bunch from one site and translate it to the next. Colored lines represent the vertical center-of-mass position of the four skyrmions, moving unidirectionally from a) black, b) blue, c) green, d) yellow to e-f) red. When the current reverses direction, the skyrmion bunch reverses direction from f-g), but requires a stronger amplitude current to push the skyrmions from site g) (green) to site h) (black), which is the same location as site (a), suggesting that a strong pinning potential exists there. Scale bar is 300 nm.

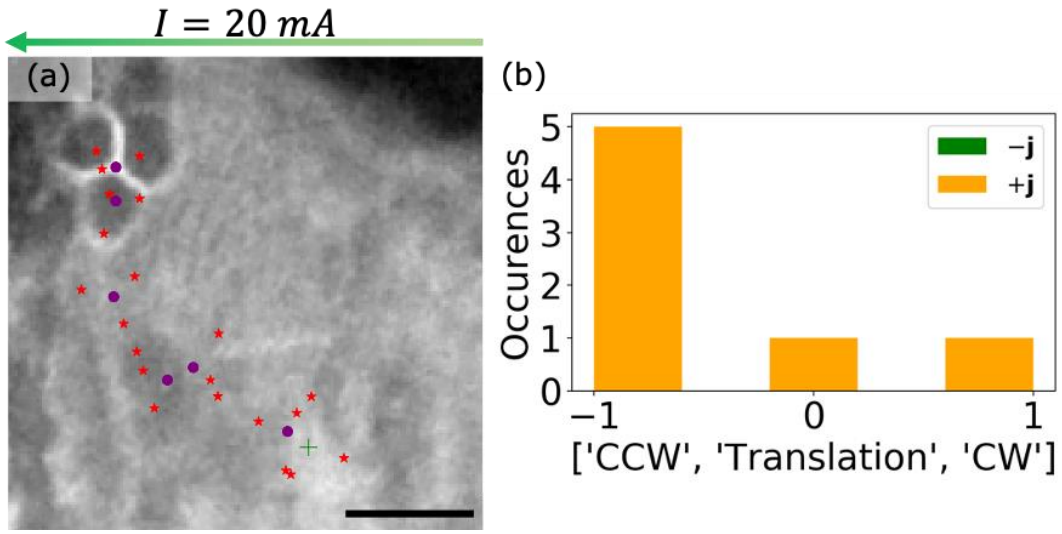


**Figure 2.** a) Three-skyrmion bunch trajectory resulting from sequential 10 µs long electrical current pulses in the direction indicated by the green arrow. The center-of-mass (CoM) trajectory is traced with purple circular markers, with a green cross marker representing the starting position and red star markers representing the individual skyrmion positions, The group Hall angle ranges from 30° and 90°. b) The rotation of the three skyrmions measured around their CoM for each frame. Scale bar is 300 nm

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