these questions. Furthermore, researchers need to identify specific inhibitors for distinct Env states, because they will indicate which conformations are neutralization-relevant targets.

As intriguing as the observations by Lu and colleagues are, much remains to be done to understand the implications fully. A conformation that predominates on native virus particles might not be a good immunogen, despite its physiological relevance, if it cannot be engineered to be stable. Furthermore, any differences between states 1 and 2 might be too small to induce different bnAb responses. Only a head-to-head comparison of vaccines using immunogens based on both Env conformations will address this point. Although state 1 immunogens are not available, upcoming vaccine trials with state 2 immunogens will bring relevant data to this debate.

Defining the relative importance of the different conformational states of the Env trimer of HIV-1 before its fusion with host cells resembles the task Dutch artist M. C. Escher carved out for viewers in his 1938 optical illusion *Three Birds* (see go.nature.com/2upmu3f). Much like choosing the most dominant colour of bird in his fluttering flock, selecting the most relevant Env conformation among the transitioning pre-CD4-bound states of the trimer depends on the context in which they are viewed. Although the differences between states 1 and 2 might be subtle, defining these states structurally and functionally is essential to inform the HIV-vaccine field. We can only be sure that the bird in the hand is indeed worth two in the bush if we seek them all out. ■

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CONDENSED-MATTER PHYSICS

Electrifying skyrmion bubbles

An electrical analogue of the magnetic-skyrmion bubble — a swirling arrangement of magnetic moments — has been unveiled in an artificially layered oxide material, raising prospects of new physics and applications. SEE LETTER P.368

PAVLO ZUBKO

Like a pesky cowlick that can't be tamed no matter how much you threaten it with a comb, tiny whorls of magnetic moments (spins), known as skyrmions and found in magnetic materials, can be extremely persistent, thanks to their specific topology[1]. And, just like hairdos, skyrmions and their various relatives come in many shapes and sizes, and with a mishmash of unusual names, such as hedgehogs, anti-hedgehogs and skyrmion bubbles. Skyrmions have been thoroughly studied since their experimental observation a decade ago[2,3] and promise denser and faster magnetic data-storage devices, but their electrical analogues have been elusive. Now, in a combined experimental and theoretical study on page 368, Das *et al.*[4] demonstrate that ordered arrays of polar-skyrmion bubbles — electrical cousins of magnetic-skyrmion bubbles — can be stabilized in artificially layered oxide materials.

Despite their fundamentally different physical origins, materials called ferroelectrics and their eponymous magnetic counterparts, ferromagnets, have many similarities. The defining property of a ferroelectric (or ferromagnet) is a spontaneous electrical polarization (or magnetization) that can be reversed by the application of an electric (or magnetic) field. This attribute makes both of these materials extremely useful for data storage, as well as for a multitude of other applications. However, unlike spins in magnets, which can often rotate with relative ease to give complex, swirling patterns, electric dipoles that arise from the relative displacements of positive and negative ions in a crystal cause a deformation of the crystal lattice, and must pay a hefty price in elastic energy to bend outside the ordered ranks.

Nevertheless, this difference hasn't stopped researchers from looking for patterns of rotating polarization in ferroelectrics, and one way to bend the rules is to go small[5–8]. When a ferroelectric is confined to the nanometre scale, it can be subject to large internal electric fields and stresses. These can strongly perturb the local polarization orientation and produce highly non-uniform distributions of electric dipoles, especially near surfaces or interfaces and domain walls, which are boundaries separating regions (domains)

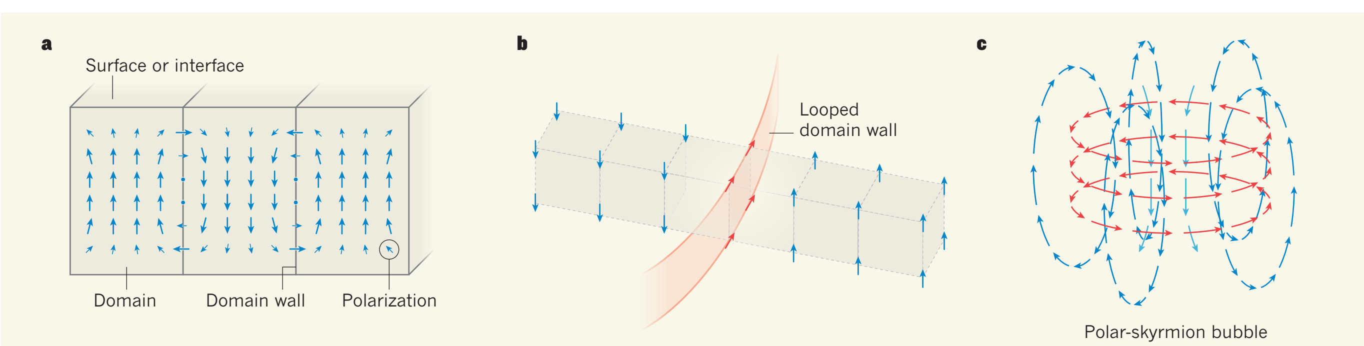

Figure 1 | The making of a polar-skyrmion bubble. **a**, When materials known as ferroelectrics are confined to the nanometre scale, they form tiny domains — regions of opposite electrical polarization. Near the top and bottom surfaces or interfaces of the material, the polarization can change magnitude and orientation, causing the polarization to rotate across domain walls. **b**, Ferroelectric domain walls can host polarization components perpendicular to those in the adjacent domains. Therefore, if such a domain wall is looped, it can form a ring of rotating polarization. **c**, Das *et al.*[4] report the observation of an exotic polarization pattern called a polar-skyrmion bubble. This pattern can be viewed as arising from nanometre-scale looped domain walls that combine the two types of polarization rotation in **a** and **b**.

that have uniform polarization orientation[9–11] (Fig. 1a). Such nanometre-scale confinement is the first ingredient for Das and colleagues' polar-skyrmion bubbles.

The second ingredient comes courtesy of a decade of breakthroughs in our understanding of the structure of ferroelectric domain walls[12,13]. It turns out that these walls can harbour polarization components perpendicular to those in adjacent domains, reminiscent of boundaries called Néel and Bloch walls in ferromagnets. Therefore, if a ferroelectric domain wall is looped, it can form a ring of polarization[14] (Fig. 1b). The direction of rotation of this polarization imparts a handedness (chirality) to the overall pattern of dipoles, making it distinct from its mirror image. Together, the rotating polarization across the domain wall and the ring of polarization within it produces the pattern of electric dipoles observed by Das *et al.* (Fig. 1c), and which has the same topology as a magnetic-skyrmion bubble.

To obtain such polar-skyrmion bubbles, Das and colleagues used artificially layered crystals called superlattices, which form ordered nanometre-scale domains. These crystals consist of alternating layers of ferroelectric and non-ferroelectric oxides, each just a few nanometres thick. To image the resulting polarization pattern, the authors used state-of-the-art electron microscopy that could resolve individual atomic displacements and produce stunning pictures of the local arrangements of electric dipoles.

A top-down view of the superlattices reveals a relatively ordered array of nanometre-scale bubbles, with in-plane polarization components converging towards the bubbles' north poles. Cross-sectional images beautifully resolve a gradual rotation from 'up' polarization to 'down' polarization across each bubble. To complete the picture, Das *et al.* used a technique known as four-dimensional scanning transmission electron microscopy to probe the swirling in-plane dipoles around the equator of a bubble that determine the bubble's chirality. The observed polarization structure is in remarkable agreement with atomic-scale simulations that reveal further details of the 3D dipole pattern.

Analogy with magnetic skyrmions is not without its subtleties. A key feature of magnetic skyrmions is their chirality, which determines their properties, including their stability and direction of motion under applied forces. This chirality stems from specific interactions that dictate whether neighbouring spins rotate in a clockwise or anticlockwise manner. Such interactions, however, have no electric counterpart.

Surprisingly, X-ray diffraction measurements by Das *et al.* reveal that the ordered polar-skyrmion bubbles exhibit macroscopic chirality. This finding poses questions about the origin of this unexpected handedness, whether it could be reversed using an applied electric field[15] and whether it affects the stability of the bubbles. Crucially, unlike spins, electric dipoles can grow and shrink in magnitude, or even disappear entirely. This property might have other implications for the stability of polar-skyrmion bubbles; these require further investigation[7,14].

The observed chiral patterns should be present in the many similar structures that have nanometre-scale domains, raising questions about the possible role of these patterns in the overall behaviour of previously investigated systems and whether their properties could be harnessed to increase functionality. Does the chiral nature of the patterns lead to any useful optical properties? Do polar-skyrmion bubbles have higher mobilities than those of stripe-like ferroelectric domains, and could they enhance the sought-after 'negative capacitance' behaviour observed in similar superlattices[16] that might help to reduce the power consumption of transistors? Perhaps they even have other unexpected properties, such as conductivity or magnetism, that are analogous to, or entirely different from, those discovered in ferroelectric domain walls[17].

The polar-skyrmion bubbles discovered by Das *et al.* necessarily form an ordered lattice to minimize the system's electrostatic energy. However, any future devices akin to the technology known as magnetic racetrack memory[18] will require the stabilization of individual polar skyrmions, as well as precise control over their injection and motion in applied fields[16]. Work in this direction will undoubtedly be a priority in this field. Irrespective of whether or not such polar-skyrmion bubbles ultimately translate into new technologies, Das and colleagues' work will kindle further excitement in the emergent study of topological ferroelectrics. ■

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50 Years Ago

The British deep sea fishing industry accepts as an inevitable part of its job an accident rate which no other industry would tolerate … The mortality rate for trawlerman, 5.7 per thousand, was twice that for all fishermen, four times that for coal miners and forty times that for the manufacturing industries … Of 2,469 men who sailed, no fewer than 693 received injuries severe enough to be recorded … Most raw recruits go to sea without training, and living conditions are bad. As recently as 1947, 31 per cent of Grimsby vessels either had no lavatories or unusable ones … And working hours once the fishing banks have been reached are extremely long — 18 hours a day is commonplace. In addition the pay structure of the industry positively encourages owners and crews to underman the boats, to continue to fish when there is a risk of foundering and to continue to work when sick or injured.
From *Nature* 19 April 1969

100 Years Ago

A note on German and English war-time diets is contributed to the Journal of the Royal Statistical Society … From the records of German towns, according to Government statistics, the average food-value in that country was 2352 Calories per head per day in April, 1916, and 2007 in April, 1917. In June, 1917, the corresponding averages of six canteens and hostels in Great Britain were 3168 and 3073 Calories, while in April, 1918, the averages for three women's munition hostels were 2782 and 2699 Calories per head per day. It should, however, be noted that the German statistics referred to the consumption of food in ordinary families, and this and other circumstances preclude any attempt at a very exact comparison of the conditions of living.
From *Nature* 17 April 1919