Annemieke Milks is in the Department of Archaeology, University of Reading, Reading RG6 6AB, UK.
e-mail: a.g.milks@reading.ac.uk

1. Barham. L. *et al. Nature* **622**, 107–111 (2023).
2. Warren, S. H. *Quart. J. Geol. Soc. London.* **67**, XCIX (1911).
3. Thieme, H. *Nature* **385**, 807–810 (1997).
4. Clark, J. D. (ed.) *Kalambo Falls Prehistoric Site: Volume III, The Earlier Cultures: Middle and Earlier Stone Age* (Cambridge Univ. Press, 2001).
5. Chu, W. *World Archaeol.* **41**, 348–362 (2009).
6. Jaubert, J. *et al. Nature* **534**, 111–114 (2016).
7. Shaw, A., Scott, B. & Pope, M. in *Repeopling La Manche: New Perspectives on Neanderthal Archaeology and Landscapes from La Cotte de St Brelade* (eds Allen, M. J. & Gardiner, J.) Ch. 4 (Oxbow Books, 2023).
8. Pruetz, J. D. & Bertolani, P. *Curr. Biol.* **17**, 412–417 (2007).

The author declares no competing interests.
This article was published online on 20 September 2023.

Condensed-matter physics

The twisted material that splits the electron

Cécile Repellin

Layers of a thin semiconductor material overlap in a particular pattern, giving rise to particle currents carrying a fraction of the charge of an electron – with potential for encoding quantum information. **See p.63, p.69 & p.74**

The search for new particles is typically associated with enormous underground particle colliders. But it can also be undertaken in a normal laboratory, by studying solids that have been cooled to extremely low temperatures. The complexity of interactions between the myriad electrons in these solids gives rise to intriguing phenomena, such as the fractional quantum Hall effect, in which a large magnetic field can make the electrons in a 2D material behave as though they have been split into three (or more) new particles. These peculiar particles, termed anyons, could be useful for quantum computing, but the magnetic field requirement is impractical. In three papers in *Nature* Cai *et al.*[1] (page 63), Zeng *et al.*[2] (page 69) and Park *et al.*[3] (page 74), and a fourth at *Physical Review X*, Xu *et al.*[4] report observations of the fractional quantum Hall effect in the absence of a magnetic field.

In most solids, electrons move so fast that their repulsion from one another affects their behaviour only minimally. The first condition for observing the fractional quantum Hall effect involves slowing down electrons until their repulsion dominates their behaviour. This feat is possible in a class of material called moiré materials, which are made by stacking thin layers of atoms together, and then twisting each layer relative to the next by a small angle (Fig. 1). The overlapped atomic lattices then create an interference pattern of alternating light and dark patches. An individual layer can be a single plane of carbon atoms (graphene), for example, or it can be a thin semiconductor, such as molybdenum ditelluride ($MoTe_2$; Mo, molybdenum; Te, tellurium), which belongs to the class of material known as transition metal dichalcogenides.

To observe the fractional quantum Hall effect, not only do electrons have to be slow but they also have to have topological properties[5,6]. This mathematical concept has a concrete physical meaning in this context: when a current flows through the material, an electrical resistance appears not only along the current, as is normally the case, but also in a direction perpendicular to it. This variant of the Hall effect occurs in the absence of a magnetic field thanks to the intrinsic properties of the material. For this reason, it is known as the fractional quantum anomalous Hall effect (FQAHE), and a material with this property is called a fractional Chern insulator. But the FQAHE requires a third condition that is even more subtle than the first two – the topological properties need to be somewhat uniformly distributed between the electrons that make up the electrical current.

Finding the three necessary ingredients for the FQAHE in the same material has been a considerable challenge. Twisted bilayer graphene was the subject of frenzied research when moiré materials were first discovered, and it was a strong candidate for the FQAHE, but the fractional quantum Hall effect in this material still requires a small magnetic field[7]. This suggests that twisted bilayer graphene lacks the third ingredient for FQAHE – its topology is not uniform enough. To solve this challenge, the authors of the four studies tapped into the large family of twisted transition metal dichalcogenides.

For the moiré slowdown to happen in $MoTe_2$, the two layers must be misaligned by an angle of 3–4 degrees. When this is achieved, a current emerges at the edge of the sample, carrying charges that each have exactly one-third of the charge of one electron. But fabricating a high-quality $MoTe_2$ sample with such a small twist angle first requires a substantial experimental effort. Once they had managed it, the authors of the four studies used various techniques to observe the FQAHE. Cai *et al.* and Zeng *et al.* probed the material's electronic properties with light, and showed that they

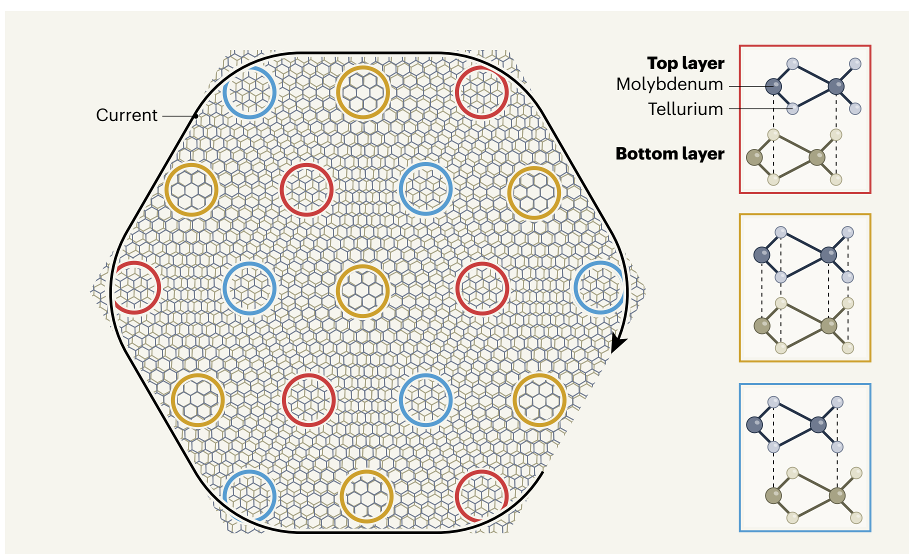

Figure 1 | Edge currents arising in twisted layers. In single-layer molybdenum ditelluride ($MoTe_2$), molybdenum and tellurium atoms are arranged in a hexagonal lattice. When two layers of $MoTe_2$ are stacked on top of one another and twisted relative to each other with a small angle, a moiré pattern emerges, resulting in dark and light patches where different atoms are stacked on top of each other. Under certain conditions, this results in a phenomenon known as the fractional quantum anomalous Hall effect, in which a current emerges at the edge of the material, carrying particles that each have one-third of the charge of one electron. Cai *et al.*[1], Zeng *et al.*[2], Park *et al.*[3] and Xu *et al.*[4] all found evidence for this effect in twisted $MoTe_2$.

responded to a magnetic field in a way that could only result from the FQAHE. Zeng *et al.* supported this conclusion with measurements of the local electronic compressibility. Park *et al.* and Xu *et al.* took a different route – creating electrical contacts of sufficient quality to enable measurement of the transverse electrical conductance that is the smoking-gun signature of the FQAHE.

The observation of the FQAHE is much anticipated in condensed-matter physics – a fundamental achievement that could have important consequences for technological applications. But there's a long road ahead to reach the next goal: controlling anyons to facilitate quantum computation[8]. Manipulating anyons generically results in a change to the quantum state of a solid, which could be used to store information. But the type of FQAHE observed so far supports only the simplest type of anyon, known as abelian anyons, and the change required to alter the quantum state is large enough only in non-abelian anyons, which are even more elusive than those observed in these four studies.

One of the paths towards generating non-abelian anyons is to connect a material containing abelian anyons to a superconductor (a material with zero electrical resistance)[9–11]. This is because superconductors can convert the edge currents of abelian anyons into non-abelian anyons. But magnetic fields tend to interfere with a material's ability to superconduct, so the revelation that abelian anyons emerge in twisted $MoTe_2$ without a magnetic field could be crucial to efforts in this direction. Creating a hybrid device comprising twisted $MoTe_2$ and a superconductor will undoubtedly generate a new set of experimental obstacles, but the creative and tireless community of condensed-matter physicists should be up to the challenge.

Cécile Repellin is in the Laboratory of Physics and Modeling of Condensed Matter, 38000 Grenoble, France.
e-mail: cecile.repellin@lpmmc.cnrs.fr

1. Cai, J. *et al. Nature* **622**, 63–68 (2023).
2. Zeng, Y. *et al. Nature* **622**, 69–73 (2023).
3. Park, H. *et al. Nature* **622**, 74–79 (2023).
4. Xu, F. *et al. Phys. Rev. X.* **13**, 031037 (2023).
5. Parameswaran, S. A., Roy, R. & Sondhi, S. L. *C. R. Phys.* **14**, 816–839 (2013).
6. Bergholtz, E. J. & Liu, Z. *Int. J. Mod. Phys. B* **27**, 1330017 (2013).
7. Xie, Y. *et al. Nature* **600**, 439–443 (2021).
8. Nayak, C., Simon, S. H., Stern, A., Freedman, M. & Sarma, S. D. *Rev. Mod. Phys.* **80**, 1083 (2008).
9. Cheng, M. *Phys. Rev. B* **86**, 195126 (2012).
10. Lindner, N. H., Berg, E., Refael, G. & Stern, A. *Phys. Rev. X* **2**, 041002 (2012).
11. Clarke, D. J., Alicea, J. & Shtengel, K. *Nature Commun.* **4**, 1348 (2013).

The author declares no competing interests.
This article was published online on 27 September 2023.

Developmental physiology

Coordinating the first heartbeat

Joshua Bloomekatz & Neil C. Chi

An impressive combination of computational modelling and experimental techniques in live zebrafish embryos reveals how the heart initiates its organized and rhythmic beating. **See p.149**

The human heart beats more than 2.5 billion times during a lifetime. But what makes it tick for the very first time? From studies of chick embryos more than a century ago through to more recent investigations in mice[1], it has become clear that the first heartbeat occurs even before formation of the primitive heart tube (the first functional structure formed during heart development). It is also known to be preceded by transient releases of calcium ions (Ca^{2+}), which initially present as spontaneous asynchronous oscillations of Ca^{2+} concentrations[2–4]. Now, on page 149, Jia *et al.*[5] exploit the unique attributes of zebrafish embryos (*Danio rerio*) – including their external fertilization, optical transparency and tractability to genetic modification – to investigate *in vivo* how Ca^{2+} waves organize and propagate across the developing heart to trigger the first heartbeats.

To capture the developmental events that lead to the first heartbeat, Jia *et al.* studied the early zebrafish heart in live embryos using a technique known as all-optical electrophysiology. In many organisms, populations of early cardiac muscle cells (cardiomyocytes) are known to develop bilaterally and migrate towards the midline (Fig. 1), and the authors observed sparse, transient bursts of Ca^{2+} in these cells in their experiments – similar to findings in mice[4].

As these cardiomyocytes merge and form

From the archive

The danger of scientific names getting lost in translation, and frog mysteries come into focus.

100 years ago

It is difficult ... to preserve orthography in scientific names derived from the Greek. A good example of the confusion which has been allowed to become inevitable occurs in the similarity of the generic title of two very dissimilar shrubs. *Chionanthus Virginica* has been named from *χιών* — snow — because of the masses of white blossom it bears at midsummer; while *Chimonanthus fragrans*, flowering in midwinter, ought to be written *Cheimonanthus*, from *χειμών*, winter. To each of these Greek generic names a Latin adjective has been tacked, which serves to distinguish the species, but may offend the scholar.

From *Nature* 6 October 1923

150 years ago

What is a Frog? At first, almost all persons will think, on meeting with this question, that they can answer it readily and easily. Second thoughts, however, will show to most that such is by no means the case ... "The Frog is a small saltatory Reptile" will probably be the reply of the majority. But *is* it a Reptile? At any rate it begins life (in its Tadpole stage) like *a Fish!* By the great Cuvier, however, as by very many naturalists since, it has been regarded as a Reptile and classed with Lizards, Crocodiles, and Serpents; and yet it may be a question whether the murine affinity connubially assigned to it in the Nursery tale, be not the lesser error of the two ... The number and nature of both the closer and the more remote allies of the Frog; its distribution both as to space and as to time; ... its bony frame-work; its muscles and nerves; its brain and sense-organs; its respiratory and excretory structures; its various changes from the egg to maturity, together with peculiarities of habit in allied forms; are all matters which will well repay a little attentive consideration. Indeed it is probable that no other existing animal is more replete with scientific interest of the highest kind, than is the Frog.

From *Nature* 2 October 1873