TOPOLOGICAL PHYSICS

A sudden twist

Floquet engineering harnesses alternating fields to create a topological band structure in an otherwise ordinary material. These fields drive plasmons that can spontaneously split into chiral circulating modes and induce magnetization.

Luis E. F. Foa Torres

During the last decade, a number of studies have reshaped the way we look at light–matter interaction. Laser illumination, or more generally a time-dependent driving, has given rise to what we call Floquet engineering: the ability to endow an otherwise normal metallic or insulating sample with a gap — or even topological states[1–3]. The name Floquet signals that we are in the realm of Floquet theory, the prevalent framework used for this type of driven system, and a temporal analogue of Bloch theory. Writing in *Nature Physics*, Mark Rudner and Justin Song have now ventured into new territory with the prediction of spontaneous non-equilibrium magnetism in driven graphene[4].

Light–matter interaction enables many of the most useful inventions, both in our daily lives and in our labs. Light-emitting diodes are everywhere in our cities, and light is our favourite tool to characterize new materials with ever-increasing precision. But mostly we use light to observe a material, while keeping the intensities low to ensure that we do not alter the sample. This is the case, for example, in Raman spectroscopy, which is often used to characterize materials (Fig. 1a).

Beyond this, light–matter interaction can also take a less passive role. Using light as a topological switch could become the leitmotif of the Floquet era (Fig. 1b): turn on the lights and the electronic structure of graphene[1,3,5] or any other material is dressed, acquiring the topological characteristics of your choice. Experiments have confirmed that a light-induced gap opens at the surface of a three-dimensional topological insulator[6] and that a laser-induced Hall effect occurs in graphene[7]. Further work has embraced this line of thought in ultracold matter and beyond. Now, Rudner and Song have highlighted that the feedback due to collective modes may bring a new drive to this field.

Consider graphene under linearly polarized driving. Floquet theory predicts how the time-dependent driving dresses the electronic states. Without further ingredients, no chiral effect emerges in this case. But as Rudner and Song put forward, besides the external field, the collective modes can completely change the picture: above a critical driving intensity, a non-vanishing Berry flux shifts and splits the

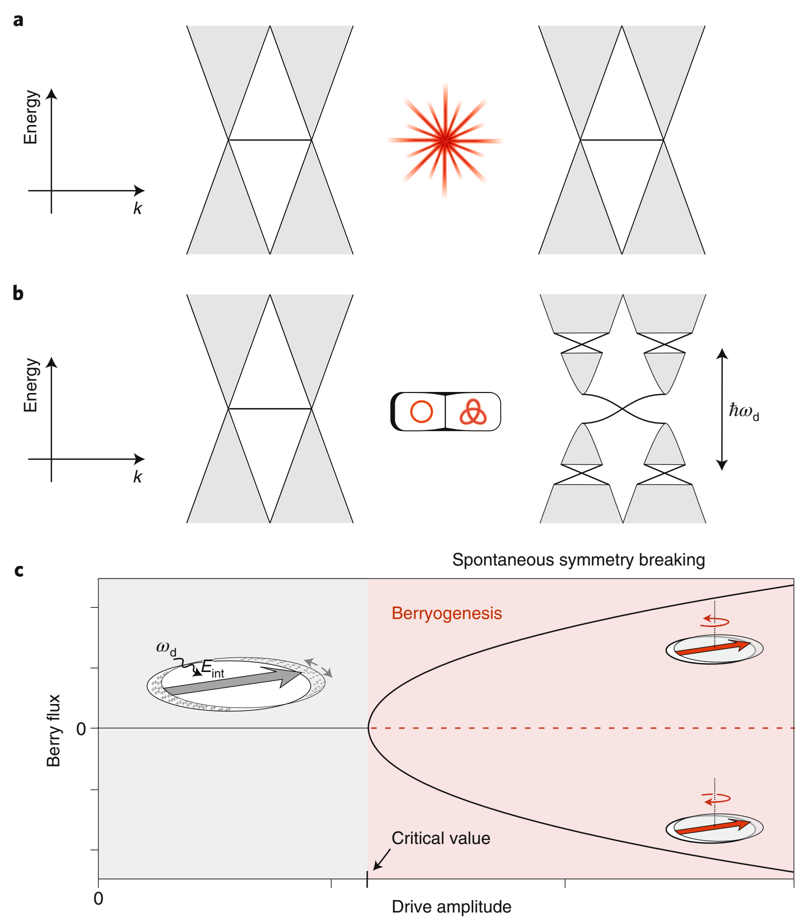

Fig. 1 | Different stages of light–matter interaction. a, In a Raman spectroscopy experiment with low laser intensity, the band structure remains unchanged and the material properties are not modified. **b**, Light–matter interaction used for active purposes, as a topological switch able to endow a material (left) with chiral edge states as shown in the Floquet quasi-energy, which is plotted versus wavevector *k* (right)[4]. Note that here the chirality is imprinted by the circularly polarized laser of frequency ω_d. **c**, One step further, a driven system can develop a Berry flux in response to a linearly polarized field. The plot shows the time-averaged Berry flux as a function of the drive amplitude for graphene. For small amplitudes, the response follows the drive and there is no Berry flux. But when the drive amplitude exceeds a critical value, so that the internal response of the system is set to dominate, the linearly polarized response becomes unstable (dashed red line) and a left- or right-handed circulation with the concomitant non-zero Berry flux emerges in a disk-shaped sample. E_{int} is the internal electric field of the disk's dipole mode (inset). Panel **c** adapted from ref. [4], Springer Nature Limited.

plasmon resonances, leading to a bistable region where the system spontaneously chooses between left- or right-handed motion (Fig. 1c). This feedback effect is the key to 'Berryogenesis' — the spontaneous generation of a Berry flux.

There are two main requirements for an experimental realization of a graphene plasmonic device[8,9] such as that proposed by the authors. The first is what prevents Berryogenesis, which relies on the coherent effects of the driving on the states, from being obscured by dissipative effects. To circumvent this problem, Rudner and Song chose a frequency corresponding to an energy less than twice the Fermi energy so that direct photon absorption was prevented by Pauli blocking. The other important point for this self-Floquet effect relies on having a strong enough internal response of the material, such that it overrules the external field. The threshold driving amplitude is controlled by the plasmonic quality factor. For the quality factors exceeding 100 that have been reported for graphene plasmonic devices[9], the authors estimated that at a driving frequency of 25 THz with a moderate intensity of about 30 W cm^{-2} on a disk of 100 nm in diameter a magnetic field of hundreds of nanotesla would be generated, which is detectable with modern techniques.

Berryogenesis marks a non-equilibrium phase transition to a situation in which a self-sustained plasmonic motion spontaneously breaks the mirror symmetry of the system. In contrast to conventional ferromagnetism, spin does not play a role in plasmonic magnetism[4]. Taking a broader view, tapping into the internal response of a material under non-equilibrium conditions might uncover a treasure trove of new physics, where long-sought-after spontaneous symmetry-breaking transitions, such as driving-induced zero resistance, could be waiting. ❐

Luis E. F. Foa Torres
Department of Physics, Faculty of Physical and Mathematical Sciences, University of Chile, Santiago, Chile.
e-mail: luis.foatorres@uchile.cl

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References

1. Oka, T. & Aoki, H. *Phys. Rev. B* **79**, 081406(R) (2009).
2. Lindner, N. H., Refael, G. & Galitski, V. *Nat. Phys.* **7**, 490–495 (2011).
3. Kitagawa, T. et al. *Phys. Rev. B* **84**, 235108 (2011).
4. Rudner, M. S. & Song, J. C. W. *Nat. Phys.* https://doi.org/10.1038/s41567-019-0578-5 (2019).
5. Perez-Piskunow, P. M., Usaj, G., Balseiro, C. A. & Foa Torres, L. E. F. *Phys. Rev. B* **89**, 121401(R) (2014).
6. Wang, Y. H., Steinberg, H., Jarillo-Herrero, P. & Gedik, N. *Science* **342**, 453–457 (2013).
7. McIver, J. W. et al. Preprint at https://arxiv.org/abs/1811.03522 (2018).
8. Koppens, F. H. L., Chang, D. E. & Javier García de Abajo, F. *Nano Lett.* **11**, 3370–3377 (2011).
9. Ni, G. X. et al. *Nature* **557**, 530–533 (2018).