magnetic fluctuations of a metal–organic compound that lacks frustration. Their study reveals the presence of an isotropic continuum, which may indicate the existence of fractional excitations. One striking feature of these results, which make them unusual and worthy of future investigations, is that this material has long-range antiferromagnetic order. The highly incoherent signal is limited to high energies, but well-defined magnon excitations are clearly visible at low energies. It should be emphasized that a more conventional scenario is also possible, in which magnons may decay or have a strong scattering due to phonons and disorder. However, it is remarkable that the experimental results are well-represented by a relatively simple theoretical approach based on Gutzwiller projected wave functions with fractional excitations. In fact, they consider an interesting variational framework to represent not only the ground state, but also the relevant excitations. In this way, a description of the dynamical spin structure factor is available and indicates that the anomaly at high-energy originates from deconfined spinons.

In our view, both the experimental results and the interpretation of the physical properties will certainly stimulate further work. First of all, it will be important to rule out possible phonon and disorder effects and confirm a bona fide fractionalization of the excitations at high energies. Moreover, the description in terms of Gutzwiller projected wave functions should be improved, to understand how accurately the experimental data can be explained by this approach. Indeed, from the variational principle, the lowest-energy state has antiferromagnetic order and does not show any evidence of fractionalization (see Fig. 4 in ref. 2). Nevertheless, a resonating valence bond state can be constructed with a reasonably low variational energy. The latter approach has a remarkable similarity with the experimental data: a broad continuum at high energies and sharper excitations at low energies.

In addition, the role played by the Gutzwiller projector is far from trivial, as there are more gapless wavevectors in the unprojected wave function than what is observed following Gutzwiller projection. What, then, is the mechanism that opens a gap for some momenta but not for others?

And why is the spectrum much broader in some regions compared with others? Some of these aspects have been considered recently in an improved variational approach, but more work is certainly required to reach a general consensus. An even more compelling question concerns the possibility of understanding and describing the proposed wavevector-selective fractionalization using well-established approaches based on field theory.

References

QUANTUM OPTICS

Spin gives direction

Light emitted near an optical waveguide is captured and equally split into two modes with opposite directions of propagation. By controlling the dipole spin of the emitter, it is possible to break this symmetry and select only one direction.

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In vacuum, an electric dipole oscillating at optical frequencies radiates light in all directions, except parallel to the dipole axis. If the dipole is very close to the lateral surface of an optical waveguide — say the core of an optical fibre — part of the radiation can be captured and channelled into the guided modes. The power of the captured light is exactly the same for the two opposite propagation directions along the waveguide — the process is symmetrical (Fig. 1a). An interesting fundamental question is how to break this symmetry and select a single direction of propagation in the waveguide, while still preserving its ability to carry light in both directions. The obvious adjustment of the radiating dipole orientation does not help: the coupling remains perfectly balanced for all possible orientations of the dipole.

A solution to this problem has been reported in several recent experimental and theoretical works. The main trick is to have the electric dipole rotate instead of oscillate. Of course, rotation is equivalent to combined oscillation in two orthogonal directions, but with the two oscillations being in quadrature — phase-shifted by a quarter of the period. The rotating dipole must also be properly oriented, meaning that it must lie in the plane containing the waveguide axis. Most importantly, the rotation direction — clockwise or anticlockwise, as seen from the side — selects which waveguide-mode direction the dipole couples to (Fig. 1b,c).

With the benefit of hindsight, this approach can have a simple physical explanation. A given propagating mode of the waveguide is associated with a well-defined distribution of oscillating electric and magnetic fields in space, both inside and outside the waveguide core. In particular, outside the core, ‘evanescent fields’ are formed and they decay exponentially with distance. The vector structure of the electric (and magnetic) field in such an evanescent wave, as determined by Maxwell’s equations, is crucial. One can show that relative to the propagation axis there are both transverse and longitudinal components in such a field. At each point in space, the longitudinal component and the transverse-radial component of the field oscillate in quadrature relative to each other.

In optical nanofibres, such as those considered in refs 1 and 2 or in photonic-crystal waveguides3,4, these two field components can be almost equal in amplitude locally, so that the total electric field resulting from their combination describes approximate circles, similar to...
those in circularly polarized light (Fig. 2). For this reason, the field is said to contain a local ‘spin density’, or intrinsic angular momentum. However, unlike the case of circular polarization, here the optical spin (or the field rotation axis) is transverse to the propagation direction, rather than parallel to it. Moreover, the rotation direction depends on the propagation direction of the waveguide mode (Fig. 2).

In a visual analogy with fluid dynamics, the evanescent circulating fields generated by a wave propagating in the waveguide resemble eddies forming at the boundary of a fluid jet. However, this analogy should not be pushed too far. For instance, eddies are discrete, whereas the circulating evanescent field is continuously distributed.

If a polarizable small object (say an atom or a nanoparticle) is placed near the waveguide, the circulating evanescent field of a given optical mode can induce a similarly circulating electric dipole in the object. By the principle of electromagnetic reciprocity, a circulating dipole in the object may excite the same mode in the waveguide, corresponding to a single propagation direction. If the circulation direction is inverted, the propagation direction of the generated mode is also reversed. However, the directional coupling is not perfect because the evanescent field does not actually describe perfect circles, but ellipses, as the amplitudes of the longitudinal and transverse fields are not identical.

The reported experimental demonstrations of these ideas differ from each other mainly in the nature of the polarizable object used as a local dipole. In the work reported by Mitsch et al., laser-cooled individual atoms are optically trapped a few hundred nanometres away from a vacuum-clad nanofibre core. A magnetic field is used to split the Zeeman atomic levels and the atoms are excited to a specific state by a circularly polarized beam of laser light aligned orthogonal to the fibre, so they emit fluorescence with a single circular transition dipole. Rather than atoms, Petersen et al.2 use a gold nanoparticle attached to the lateral surface of the nanofibre core. The nanoparticle scatters the circularly polarized light of an orthogonally aligned laser beam into the fibre. Finally, Le Feber et al.3 use the probe tip of a scanning near-field optical microscope (SNOM) as a dipole source, which is placed a few nanometres from the photonic-crystal waveguide to which light is to be coupled and excited by injecting circularly polarized light into the SNOM. In contrast, the two theoretical works consider the case of quantum dots emitting with circular transition dipoles directly inside the core of a photonic-crystal waveguide, rather than in the evanescent field region.

The fact that light-spin, or more generally the vector structure of the field, controls the subsequent propagation of the optical wave can be viewed as a manifestation of spin–orbit optical coupling. Whereas in standard paraxial optics the polarization and wave propagation are separate properties of the light with essentially no interaction (excluding anisotropic media), a growing number of optical phenomena in which this interaction plays an important role — ranging from strongly non-paraxial optics, nano-optics, plasmonics or propagation in complex optical media — are currently being discovered.

Besides providing a striking example of spin–orbit optical phenomena, the reported results may also find application in classical or quantum photonic systems requiring a fully controllable interfacing between light and localized material excitations — such as, for example, quantum memories, processors or networks.

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