OPTICS

Negative reaction

Light pulses with positive and negative effective masses are now generated using optical fibres. Nonlinear interactions between the two can then create self-accelerating pulse pairs, opening a new route to pulse steering.

Thomas Philbin

Newton's third law states that in a two-particle interaction the forces on each body are equal and opposite. This action–reaction principle may seem intuitive, but its reasonableness relies on our natural idea that mass is always positive. Equal and opposite forces generate oppositely directed accelerations only because mass has just one sign. If two stationary particles with masses of equal magnitude but opposite sign interact in accordance with the action–reaction principle, then the particles will accelerate in the same direction, maintaining a constant separation (Fig. 1). Negative-mass particles have long intrigued theorists[1] but remain fictional. On the other hand, negative-mass quasiparticles are real phenomena in condensed-matter and light–matter systems. Now, writing in *Nature Physics*, Martin Wimmer and his colleagues describe how they created light pulses with effective masses of either sign using optical fibres[2]. Action–reaction forces arise between the pulses owing to fibre nonlinearity. This enabled them to observe two interacting pulses with effective masses of opposite sign forming a self-accelerating bound state.

Despite our modern notion of light as massless relativistic particles, light propagation in materials is routinely treated in terms of the dynamics of massive particles obeying Newton's laws[3]. Photonic-lattice structures offer a way of controlling the effective mass of these light 'particles' because their dispersion relation can be engineered. A band that curves upwards in a plot of frequency versus wave vector has positive effective mass, whereas a band that curves downwards exhibits negative mass. Light pulses of both positive and negative effective mass may therefore populate a photonic lattice. But the self-accelerating bound state requires more than just control over effective mass; it also requires a mutual force between pulses. This can be induced by the optical nonlinearity of the material in the region where the pulses overlap.

Spatial mesh lattices — arrays of waveguides that are periodically coupled to their nearest neighbours — inspired the photonic structure used by Wimmer and the team. Instead of using spatial slots in the waveguides, however, the mesh was created by a train of slots in time, an arrangement called time multiplexing[4,5]. The time slots are set up in a loop of optical fibre; the slots move along the fibre with each one either empty or containing a pulse. To mimic the spatial mesh, the time slots must couple to their nearest neighbours. This coupling is achieved using a second fibre loop of different length, coupled to the first loop at one point. The differing loop lengths delay the time slots in one loop by one slot length compared with the other loop. Nearest-neighbour time slots are thus coupled to each other at the point where the loops meet, which mimics exactly the spatial mesh lattice and its dispersion relation.

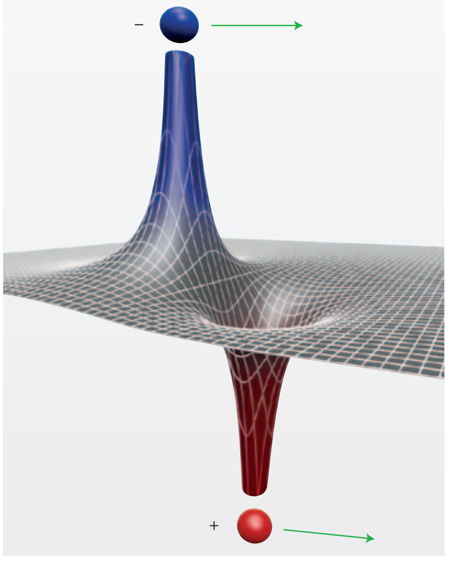

Figure 1 | Self-accelerating particles. If two interacting bodies have masses with opposite sign, they accelerate in the same direction. Figure courtesy of C. Bersch and M.-A. Miri.

Wimmer and co-workers inserted wave packets consisting of trains of pulses in the time slots. As required, the dispersion relation of this time-multiplexing arrangement exhibits two bands of opposite curvature, representing wave packets with positive or negative effective mass. In addition, the Kerr nonlinearity of the fibres introduces the necessary mutual attractive force between wave packets that partially overlap. Thus the team could show that two wave packets of opposite mass, exerting equal and opposite forces on each other, form a self-accelerating bound state; a dramatic demonstration of negative mass combined with Newton's action–reaction principle.

In a second experiment, the team created an effective potential for the wave packets using an external phase modulation. A potential well induces a force on the wave packets that is directed towards the potential minimum, but the direction of the acceleration depends on the sign of the effective mass. Wave packets with positive mass are attracted to the centre of the well, whereas negative-mass packets are repelled by the same potential.

These results are another example of a familiar lesson in physics: basic principles can successfully describe and control very complicated systems. But this can involve pushing these principles beyond what was permissible in their original domain. Other systems may prompt similar extensions of our thinking about basic mechanics. ❐

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References

1. Bondi, H. *Rev. Mod. Phys.* **29,** 423–428 (1957).
2. Wimmer, M. *et al. Nature Phys.* http://dx.doi.org/10.1038/nphys2777 (2013).
3. Born, M. & Wolf, E. *Principles of Optics* 7th edn (Cambridge Univ. Press, 1999).
4. Bouwmeester, D., Marzoli, I., Karman, G., Schleich, W. & Woerdman, J. *Phys. Rev.* A **61,** 013410 (1999).
5. Schreiber, A. *et al. Phys. Rev. Lett.* **104,** 050502 (2010).

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