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QUANTUM PHYSICS

Entangled vibrations in mechanical oscillators

Two experiments have demonstrated entanglement — non-classical correlations — between remote mechanical systems comprising billions of atoms. The results could advance our understanding of quantum physics. SEE LETTERS P.473 & P.478

ANDREW ARMOUR

In the quantum world, the properties of particles can be correlated in an extremely strange way. Measurements on one particle can influence the properties of another, even if the two particles are far apart. Such behaviour is known as entanglement and was initially so paradoxical that many people, including Albert Einstein[1], thought that the underlying theory must be incomplete. However, experiments have verified the counter-intuitive properties of entanglement[2], and physicists have got used to the idea, recognizing that it could be exploited to develop innovative forms of technology. On pages 473 and 478, respectively, Riedinger *et al.*[3] and Ockeloen–Korppi *et al.*[4] take the exploration of entanglement in a new direction. They entangle the vibrations of a pair of remote mechanical oscillators, each of which contains billions of atoms.

Mechanical oscillators, such as a mass on a spring or the head of a drum, are familiar objects. They respond to being pushed out of equilibrium by vibrating back and forth at a fixed frequency. Because motion can be generated in lots of different ways — using light, electrical currents or even gravity — mechanical oscillators are highly versatile. Consequently, they have many applications, for example in the detection of weak forces[5].

Uncovering signatures of quantum

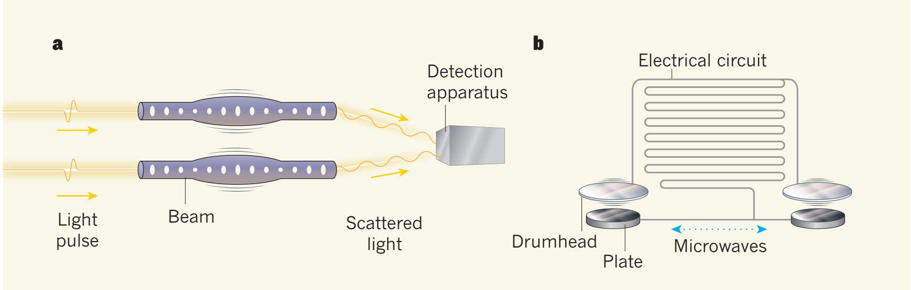

Figure 1 | Entanglement of two types of mechanical oscillator. Riedinger *et al.*[3] and Ockeloen–Korppi *et al.*[4] report entanglement (non-classical correlations) between the vibrations of two remote micrometre-scale mechanical oscillators. **a**, Riedinger and colleagues used oscillators in the form of silicon beams. Each beam contained small holes designed to trap light, that coupled to rapid oscillations in the beam's width. The authors achieved entanglement by shining pulses of light on the beams and detecting the light that was scattered. **b**, By contrast, Ockeloen–Korppi and colleagues used metal drumheads that vibrated up and down above fixed metal plates. The drumheads and the plates were connected by an electrical circuit. The authors injected microwaves into the circuit; these bounced back and forth between the oscillators, coupling the drumheads and giving rise to entanglement.

behaviour, such as entanglement, in mechanical oscillators is exceptionally challenging — largely because it is difficult to prevent these objects from being disturbed by their surroundings. The oscillators usually have low vibrational frequencies and are therefore susceptible to disruption from the thermal jiggling of surrounding atoms. By contrast, the electromagnetic field associated with light has extremely high-frequency oscillations, which means that light is completely insensitive to thermal fluctuations at room temperature. As a result, it is relatively easy to control the properties of light with the exquisite precision required to reveal quantum effects, and the production of entangled light has become almost routine.

The experiments of Riedinger *et al.* and Ockeloen–Korppi *et al.* differed in detail, but shared several key ingredients. To counter the effects of thermal fluctuations, both groups of authors used micrometre-scale mechanical oscillators, which ensured that the vibrational frequencies were not too low, and cooled the oscillators to temperatures of less than 0.1 kelvin. In both experiments, electromagnetic radiation (in the form of light or microwaves) provided the means to generate and detect the entanglement of the oscillators[6,7].

Riedinger and colleagues used a pair of oscillators in the form of 10-μm-long silicon beams — rods that were clamped at both ends and suspended in the middle (Fig. 1a). Each beam contained small holes designed to trap light, that coupled to rapid oscillations (with frequencies of about 5 gigahertz) in the beam's width. The authors shone weak pulses of light on the beams, and monitored the light that was scattered, using a sophisticated scheme that did not reveal which beam the light came from. The detection of such light meant that energy had been transferred from a pulse to the vibrations of a beam, but because there was no information about which oscillator was involved, the vibrations of the two beams were entangled.

The trick of using light to generate entanglement in this way[8] works only if the light scatters from objects that are almost perfect copies of each other. This is difficult to achieve using small mechanical beams, because such objects are produced by a destructive process in which they are essentially sculpted out of a monolithic slab of material. Riedinger *et al.* therefore produced chips containing hundreds of beams from which they selected the best-matched pair.

Ockeloen–Korppi *et al.* used a pair of metal drumheads that vibrated up and down above fixed metal plates (Fig. 1b). The drumheads had diameters of about 15 μm and low vibrational frequencies (about 10 MHz). The authors connected the drumheads by an electrical circuit in which microwaves could bounce back and forth. The microwaves influenced the motion of the drumheads, but were also affected by this motion, coupling the oscillators in the same way that a spring can link two pendulums. This allowed an entangled state to form, and to persist indefinitely, despite the low vibrational frequencies of the drumheads[9].

Taken together, these two experiments provide an elegant illustration of the power and versatility of electromagnetic radiation as a tool for exploring quantum features of mechanical motion. Each experiment has its advantages. Riedinger and colleagues' beams interface directly with light and are not connected by wires, which means that these devices could be readily integrated into future optical communication networks designed to exploit the effects of entanglement. Ockeloen–Korppi and colleagues' results are particularly striking, given the low vibrational frequencies that they used; and their approach avoids the need for mass fabrication, because the oscillators need not be almost identical.

It was only in 2009 that entanglement was first reported between mechanical oscillators consisting of just two atomic ions[10]. Since then, experiments have demonstrated entangled vibrations in the lattices of crystals[11], at frequencies much higher than even those of Riedinger and colleagues' beams. In terms of the number of atoms involved, the oscillators used by Riedinger *et al.* and Ockeloen–Korppi *et al.* are both a big step up from atomic ions, but they are still much smaller than the macroscopic objects encountered in everyday life. It will be fascinating to see how much further up in scale experiments are able to go in the next decade. Such progress could lead to exciting insights — for example, larger mechanical oscillators in entangled states might provide answers to outstanding questions about how gravity relates to quantum physics[12]. ■

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NEUROSCIENCE

Hunger is a gatekeeper of pain

A neuronal population has now been found that regulates two competing needs — hunger and pain. Urgent pain overrides hunger, but appetite-inducing neuronal activity dampens long-term pain responses to enable feeding.

ALEXEY PONOMARENKO
& TATIANA KOROTKOVA

The body's basic needs include a timely supply of nutrients and the avoidance of tissue damage, which are signalled in the brain by hunger and pain, respectively. But these needs cannot be fulfilled simultaneously, because their resolution involves mutually exclusive behaviours. How does the brain prioritize the more urgent need? Writing in *Cell*, Alhadeff *et al.*[1] report that the brain's priorities are set depending on the type of pain involved. Hunger-mediating neurons suppress long-term inflammatory pain, but acute pain, which signals an immediate threat, dampens the activity of these neurons and thus deprioritizes feeding.

Alhadeff and colleagues deprived mice of food for 24 hours, and analysed how the hungry animals responded to pain. The researchers found that responses to long-term inflammatory pain — of the type associated with chronic disease and recovery from injury — were reduced in the food-deprived animals compared with controls. By contrast, short-term responses to acute pain that was induced by chemicals, heat or force remained intact in hungry mice.

The brain's hypothalamus contains several structures involved in regulating food intake. One of these, the arcuate nucleus, harbours a population of neurons that express agouti-related protein (AgRP), and help to signal nutritional needs — activation of these neurons evokes voracious feeding[2], whereas their ablation leads to starvation[3,4]. Alhadeff *et al.* found that stimulation of the AgRP-expressing