variables combined in numerous ways. There is also the issue of scale and how to measure isolation, a challenge that applies to the geographic and the climatic space alike.

Understanding the dynamics of species diversity and the mechanisms through which correlations arise between climate, area and isolation also emerge as remaining challenges for future work. It is possible that, at regional scales, climate and energy availability constrain the number of species that a given area can sustain. At global scales, however, diversity patterns might be governed by the dynamics of species origination, extinction and dispersal. Consequently, tropical climates, which have existed continually for a longer time and cover larger areas than other climates, might serve as the engine of diversity[3], whereas temperate climates – which have less energy and fewer resources for species coexistence – might be constrained in their diversity[4].

Some research, however, has indicated that the opposite might also apply[5]. The comparatively newly opened temperate climates might have the capacity to accumulate new species at high latitudes, whereas the tropics might have had enough time to approach the energetic constraints on species diversity[6]. Although global differences in diversity dynamics are expected, their exact nature remains a point of contention[4,7].

Coelho and colleagues introduce a method that explicitly quantifies area and isolation across various climate types. Rigorously defining tropical and temperate areas might produce more meaningful cross-climatic comparisons, inform the scale-dependence debate and begin to identify the mechanisms that generate the correlations between diversity, climate, area and isolation.

Studying diversity in both geographic and climatic spaces opens up a treasure trove of new patterns to test theories. A true test of a theory is its universality, and the authors demonstrate how climatic space might serve as a common currency, transcending geographic boundaries, continents, latitudes and elevations. Coelho and colleagues present a fresh canvas on which to explore diversity patterns, and thereby invite researchers to delve deeper, explore further and pursue a more profound understanding of Earth's biodiversity. This quest has become increasingly important in today's world.

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Quantum physics

Searching for phase transitions in the dark

Edoardo Baldini

An electrically insulating quantum material turns metallic when placed between two semi-reflecting mirrors – even if there is no illumination between them. This discovery paves the way for engineering other phase transitions. **See p.487**

Take a conventional laser apart and you will find an arrangement of mirrors called an optical cavity, which is a structure that traps light at certain frequencies to form standing waves. A different class of optical cavity can be engineered to manipulate simple quantum systems[1,2] – to tweak the chemical reactivity of a molecular complex, for example[3]. Remarkably, this control can be achieved without any external illumination, even though it involves tuning interactions between light and matter. On page 487, Jarc *et al.*[4] have shown a glimmer of success in extending this principle to more complex quantum solids[5,6], by reporting a cavity that can offer reversible control over an archetypal phase transition.

The authors studied tantalum disulfide, a material with peculiar star-shaped charge patterns that are induced by the cooperation between its ions and electrons. The ordering of these clusters is thought to have a pivotal role in certain phase transitions, particularly one in which the material transforms from metallic to electrically insulating as the temperature changes. This transition, and the material's sensitivity to external stimuli, make tantalum disulfide an ideal platform for exploring the concept of cavity engineering in the realm of quantum matter.

In Jarc and colleagues' experiments, a thin sample of tantalum disulfide was carefully positioned between two semi-reflecting metallic mirrors (Fig. 1). The mirrors were mechanically adjustable, so their separation and alignment could be controlled precisely, creating a tunable cavity that was able to sustain standing waves that span sub-micrometre to centimetre wavelengths. Jarc and colleagues began by using a faint stream of photons to measure the conductivity of the tantalum disulfide sample as they altered the configuration of the mirrors. The photon stream was generated at a frequency that could probe the insulator-to-metal transition, while minimizing disturbance to the electromagnetic environment in the cavity. It served solely to detect any possible cavity-induced phenomena.

This approach yielded a remarkable discovery: a cavity tuned to resonate in the gigahertz frequency range brought about a pronounced – and rather surprising – modification to the thermodynamics of the insulator-to-metal transition. Specifically, the authors were able to switch back and forth between the metallic and insulating phases simply by tuning the cavity length and its mirror alignment. The transition could be induced without the authors having to manually change the temperature. The physical parameters of the cavity itself had become tuning knobs for the material's electronic properties.

Jarc *et al.* investigated whether their observations were a result of black-body radiation arising from the proximity of the mirrors, but they ruled out this possibility because it could not fully explain the change in transition temperature. Instead, the measurements led them to conclude that quantum electrodynamic phenomena were responsible for the effect.

There are two known pathways through which a cavity can affect a phase transition. The first involves the sample exchanging heat with the cavity and with the environment around the cavity. In this case, the quantum electrodynamics of the cavity do not alter the intrinsic material properties of the sample, but rather they reconfigure how heat is transferred from the surrounding environment to the sample. This process causes a change in the emission spectrum of the sample and thus in its temperature, enabling the phase transition to be manipulated. It bears a resemblance to a phenomenon known as the Purcell effect, in which a quantum system's tendency to spontaneously emit radiation varies inside a cavity[7].

The second possibility is that the cavity

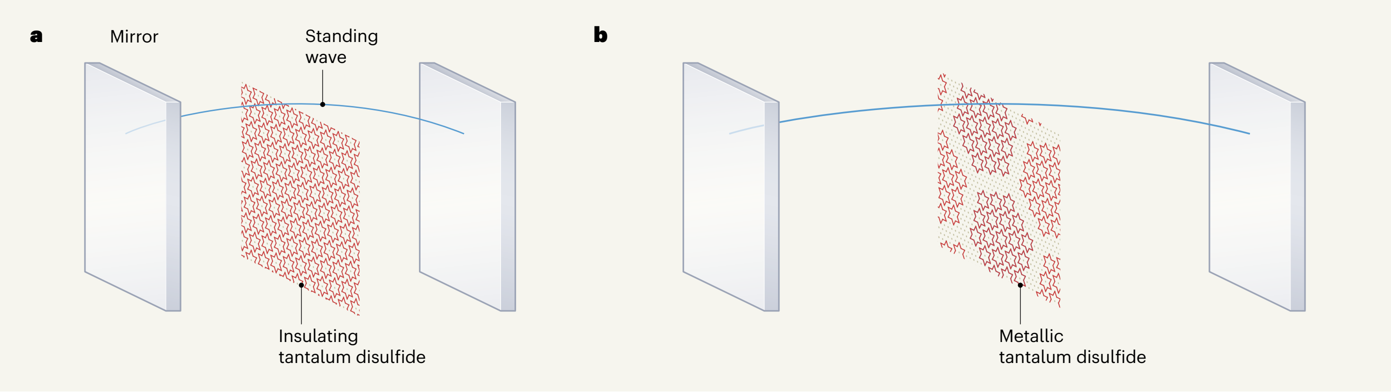

Figure 1 | Inducing an insulator-to-metal transition. The atoms in tantalum disulfide are arranged in star-shaped clusters that reorganize when temperature changes the material from being electrically insulating to metallic. **a**, Jarc *et al.*[4] placed a thin sample of insulating tantalum disulfide between two semi-reflecting metallic mirrors that were configured to generate standing waves. **b**, The authors found that they could turn the material into a metal by changing the separation (or alignment; not shown) of the mirrors, at a fixed temperature.

is isolated from its surroundings. However, according to quantum electrodynamics, the cavity is not devoid of photons. It is a vacuum, but there are electrodynamic fluctuations present, and these fluctuations manifest themselves as 'virtual' photons flitting in and out of existence. Under certain conditions, these photons can combine with excitations in the material and possibly change the energy of the states accessible to it, altering the macroscopic physical properties of matter[2]. Whereas the Purcell-like effect is known as the weak-coupling limit, the alternative is called the strong-coupling limit.

To identify the mechanism at play in tantalum disulfide, Jarc and colleagues simultaneously monitored the temperature inside and outside the cavity while changing the alignment of the mirrors. To do so, they placed a minuscule thermometer in direct contact with the material to minimize the disturbance on the cavity environment – a precise and effective means of obtaining this information. Their measurements showed that the temperature of the sample changed considerably in the cavity. This suggests that the authors' ability to tune the insulator-to-metal transition was made possible by the Purcell-like effect, in which the cavity quantum electrodynamics mediate the exchange of heat between the sample and its surroundings.

Jarc and co-workers' results serve as an exceptional proof of principle, showcasing how cavities with no artificial illumination can trigger phase transitions. However, numerous questions remain regarding the mechanism behind the detected phenomena. The Purcell-like scenario falls short of providing a quantitative explanation for the substantial changes of the sample's temperature in the cavity environment.

This raises the enthralling possibility that strong-coupling phenomena arising from the vacuum photons might also be relevant, even though the authors' cavities are not designed to operate in the strong-coupling limit. Indeed, the collective excitations that naturally arise in tantalum disulfide at gigahertz frequencies could potentially enhance the interaction between cavity and sample, driving the system to this limit. Verifying this possibility would require identification of these excitations, which are probably related to collective deformation modes associated with the star-shaped clusters of tantalum disulfide[8].

Jarc and colleagues' discovery represents a rigorous and crucial stride towards understanding the electrodynamics of complex solids embedded in an optical cavity. More generally, investigations into the effect that vacuum fluctuations have on phase transitions are ongoing[9], and could have wide-ranging implications. For example, evidence that vacuum photons affect macroscopic quantum phenomena such as long-range order, coherence and entanglement would bring into question the way in which these effects manifest in cooperative quantum matter. The search in the dark continues.

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Immunology

Inflammation insights for a deadly bacterium

Klaus Aktories

Infection by the bacterium *Clostridioides difficile* can be fatal in a clinical setting. Insights into the molecular mechanisms underlying such infection might offer targets for the search to develop new treatments. **See p.611**

A key unwanted complication of antibiotic use is that disrupting the natural bacterial community in the human gut might enable infection by the harmful bacterium *Clostridioides difficile*. On page 611, Manion *et al.*[1] shed light on some of the inflammation-associated events that occur during *C. difficile* infection (CDI).

The proliferation of *C. difficile* in the gut can lead to mild to severe diarrhoea or to pseudomembranous colitis, a severe illness with potentially lethal complications such as toxic megacolon or bowel perforation[2]. Moreover, the frequency of recurrent infections and the