twist angle or different amount of strain. Transport measurements also are restricted to addressing electrons at the Fermi level, with the rest of the band structure remaining inaccessible. Therefore, to gain insight at the microscopic level into the interplay of the key parameters (carrier density, twist angle, strain) as they give rise to the correlated states, local scanning probes are necessary. Scanning tunnelling techniques provide atomically resolved structural and electronic details and can visualize the symmetries of the electronic wave functions as they evolve through the phase diagram upon changing carrier densities or twist angle.

Choi and colleagues fabricated twisted bilayer graphene placed in proximity to a graphite gate, which is used to adjust the number of charge carriers. The twisted bilayer graphene is a highly tunable material system, allowing the authors to explore the evolution of its electronic states with the carrier density in the same sample, using the gate, without the complications that chemical doping would typically induce.

Spatial topographic maps are able to resolve both the atomic lattice of graphene as well as the moiré pattern formed by the twist. The rotation angle is deduced from the size of the pattern. Close to the largest magic angle, the moiré pattern can be as big as 13 nm, much greater than the bond length between the carbon atoms. Within a moiré pattern, one finds periodically varying stacking of the atoms from the two layers. The experiments can directly visualize that most of the electronic states of the flat bands are localized at places where the carbon atoms are in registry. Measurements of the microscopic details of the moiré superlattice also confirm the presence of strain, suggestive as a possible origin for the device-dependent fine features.

Measuring the differential tunnelling conductance probes the density of states. Consistent with previous reports, Choi and colleagues find the angle-dependent Van Hove singularities as peaks in their spectra. Taking advantage of the electronic gate, they then track the evolution of the peaks with carrier concentration. The important observation is that placing the Fermi level in one of the flat bands modifies the density of states, which is suggestive of the strong effect of correlations. This is in contrast with the regimes where flat bands are completely filled or empty. Interestingly, the changes in the density of states occur at certain moiré filling factors and could be an insight into the nature of the correlated effects. The size of the energy gaps measured in the tunnelling experiments differ from those found in transport experiments, underscoring the important role of strain and disorder. Through this local probe experiment, Choi and co-workers provide further insight by spatially mapping the density of states at the charge neutrality point. They suggest that the observed anisotropy is indicative of broken three-fold rotational symmetry. The results are supported by a theoretical framework based on a ten-band tight-binding model that captures the flat bands while preserving all symmetries[10].

As the field of twisted two-dimensional materials rapidly evolves as a venue for exploring correlated electronic states, local scanning probes will be invaluable in deciphering the interplay of all relevant parameters. ❐

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PRECISION SPECTROSCOPY

The magic in molecules

The demonstration of high-resolution spectroscopy of Sr_2 molecules trapped in an optical lattice at the 'magic' wavelength opens the way to precision control of molecular excitations.

Nicola Poli

Compared with atoms, molecules possess a host of additional internal degrees of freedom, including vibrational and rotational excitations on top of electronic ones. Precision spectroscopy of molecular quantum states would be a unique tool for tests of fundamental physics[1,2] and for understanding interactions among molecules at the quantum level[3]. But tackling the complexity of molecular spectra — pinning down all their possible internal excitations — is not an easy task. For example, the short coherence times of molecular quantum levels limit their interaction with the coherent laser used to probe them. Now, writing in *Nature Physics*, Stanimir Kondov and co-workers have shown that the coherence time of vibrational states of Sr_2 molecules can be significantly extended, without affecting the electronic and vibrational state itself[4].

Recently, the promise of molecular precision spectroscopy has prompted researchers to extend to molecules some of the techniques developed for atoms, which allow coherent control of both internal and external degrees of freedom with laser light. These efforts have already produced new molecular optics tools, for example the laser cooling of ultracold molecules near absolute zero[5].

In line with this development, Kondov and co-workers have introduced a method that represents a clever generalization of a well-known technique in the field of cold-atom spectroscopy, mostly implemented in today's most accurate optical lattice clocks[6,7]. They induced a 25-THz transition between two vibrational states of Sr_2 with a two-photon Raman excitation of cold molecules trapped in an optical lattice. With a proper choice of the trapping magic wavelength, they were able to compensate for the differential shift induced by the lattice itself onto the two vibrational states (Fig. 1). Under these conditions, the molecules are tightly confined at low temperatures (a few

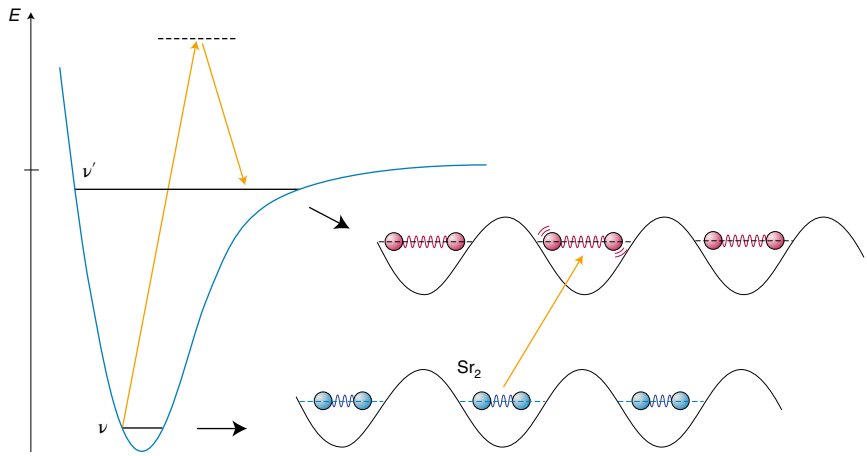

Fig. 1 | Lamb–Dicke spectroscopy of Sr_2 molecules trapped in an optical lattice. The two vibrational states at frequencies ν and ν' are coupled via a two-photon transition using visible laser radiation (orange arrows, left). Spectroscopy is performed on molecules trapped in an optical lattice tuned at the magic wavelength. In this condition, the effective 25-THz transition is unchanged, since the AC Stark shift on the two vibrational states due to the trapping light is perfectly compensated (bottom right).

microkelvin), their centre-of-mass motion is quantized and the recoil from the probe lasers can be neglected.

Although a similar technique has previously been used for spectroscopy of different molecular electronic states[8], Kondov and co-workers found a different solution for scalar clock vibrational states within the same electronic potential. In particular, they exploited the effect of an additional quasi-resonant coupling of the ground vibrational clock state with an upper rotational state in order to perfectly compensate the total AC Stark shift on the vibrational clock transition.

They then performed spectroscopy on about 5,000 ultracold Sr_2 molecules trapped in an optical lattice tuned to the magic wavelength. Under these particular conditions, the coherence time in the observed Rabi oscillations increased by more than a factor of 1,000, reaching 30 ms. The experimental quality factor of the 25-THz transition approached 10^{12}, a record in this region of the electromagnetic spectrum.

The single-photon scattering from an intense near-resonant lattice field might be a potential source of decoherence, which Kondov and co-workers studied in detail, showing that the two-photon photodissociation processes are the main cause of coherence loss. Higher coherence times could be achieved by using colder molecules and reducing the trap intensity or via coupling to more favourable intermediate molecular states and dissociation continua. Finally, to realize a fully functional molecular clock, the probe light shift effect needs to be eliminated. By carefully balancing the intensity ratio of the laser beams, its uncertainty could be reduced to the 10^{-15} level in relative units.

The magic lattice employed by Kondov and co-workers represents another step forward in the field of molecular spectroscopy, and its extreme precision will inspire further experimental work. Molecular clocks might find application in extremely sensitive measurements of interatomic forces and precision tests of Newtonian gravitation at short distances[1], model-independent tests of the variation of the electron-to-proton mass ratio[2] and in tests of quantum electrodynamics in bound systems[9,10]. ❐

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CHIRAL FLUIDS

Model oddity

A model fluid comprising rotating magnetic particles behaves according to the equations of hydrodynamics, but for a few key differences due to broken mirror symmetry. The resulting active chiral fluid is characterized by parity-odd Hall viscosity.

Alexander Abanov

Humans are fascinated by rotation. As children, we delight in merry-go-rounds, marvel at the rotation of the planets, and then later puzzle over the physics of gyroscopes. As physicists, we are adept at making sense of the things that intrigue us by building models, be they thought experiments or actual physical systems that can be measured. A fascination with rotation might prompt one to imagine what would happen if millions of interacting particles were made to spin synchronously