ATOMIC GASES

Noble-gas and alkali spins exchange excitations

Noble gas nuclear spins can store quantum information for hours but are hard to control. Creating a large coherent coupling to an alkali vapour gives a route to manipulating the collective nuclear spin of a helium-3 gas.

Alice Sinatra

The nuclear spins of noble gases are extremely well protected from decoherence by their complete electronic shells. This yields special quantum systems that can maintain their coherence for hundreds of hours[1]. The downside of this isolation is that the nuclear spin is difficult to access and control. Now, writing in *Nature Physics*, Roy Shaham and co-workers have achieved strong coupling between the nuclear spins of helium-3 and the more accessible degrees of freedom in an alkali vapour[2], which could be used to control the nuclear spin state.

The ground state of helium-3 is separated from the first excited state by 20 eV. The lack of laser sources at this frequency is an obstacle to its optical manipulation. Potassium, on the other hand, has convenient optical transitions that can be used to indirectly polarize the helium nuclear spin by a process called spin-exchange optical pumping[1]. This technique uses circularly polarized light to induce an electronic polarization in the potassium vapour, which is slowly transferred to helium by spin-exchange collisions. By exploiting the Faraday rotation effect on a linearly polarized probe beam crossing the medium, the precession of the potassium spin can be optically monitored, and the potassium can even serve as a magnetometer and sense the precession of the collective nuclear spin of the helium gas.

The spin-exchange interaction used in the optical pumping method also mediates a coherent coupling between the the alkali spin and the noble gas nuclear spin[3]. From a quantum technologies perspective, the alkali atoms are thus well suited to serve as a link between the easily manipulable optical modes that can be used to transmit information and can be measured at the quantum noise limit, and nuclear spins that are hard to access but can store information for long times. The ability to tune the coupling strength between the potassium and helium spins to the strong coupling regime, where coherent exchange between them is faster than relaxation, enriches our toolbox and opens new perspectives for light–matter quantum interfaces.

The conditions of Shaham and co-workers' experiment combine several atmospheres of helium-3, a few pascals of potassium and tens of torr of nitrogen, in a cell of almost 10 cm^3 heated to 230 °C. Besides the spin-exchange interaction already mentioned, many collisional processes occur constantly that are in principle a source of decoherence. The most important ones are spin-exchange collisions between potassium atoms that introduce transverse spin relaxation when the spins precess in a magnetic field, by changing the hyperfine state of the atoms, and potassium–potassium and potassium–nitrogen spin-destruction collisions where spin angular momentum is lost into the rotational angular momentum of the colliding pair. For a cold atoms physicist, such conditions seem akin to a barbaric battle. But it is not so: when the gases are polarized in a weak magnetic field, two coupled degrees of freedom emerge that are equivalent to two harmonic oscillators that can be set into resonance under proper conditions so that they periodically exchange energy quanta (Fig. 1).

Let us consider how this may be possible. First of all, in a low-enough magnetic field where the frequent potassium–potassium spin-exchange collisions are faster than the Larmor precession, the potassiums behave as effective spin-half systems not suffering from decoherence due to spin exchange[4]. This allows the emergence of the degree of freedom corresponding to the alkali collective spin transverse excitation that, with the helium nuclear spin, will make our quantum system. A controlled amount of excitation can be put into the system by tilting the polarized alkali spin by a small angle with a pulse of a transverse magnetic field.

The next task is to couple the two modes together strongly enough to overcome any sources of decoherence. Single spins of helium and potassium in a given magnetic field precess at very different frequencies because the gyromagnetic factor for the electron spin is a thousand times bigger than for the nuclear spin. However, it is possible

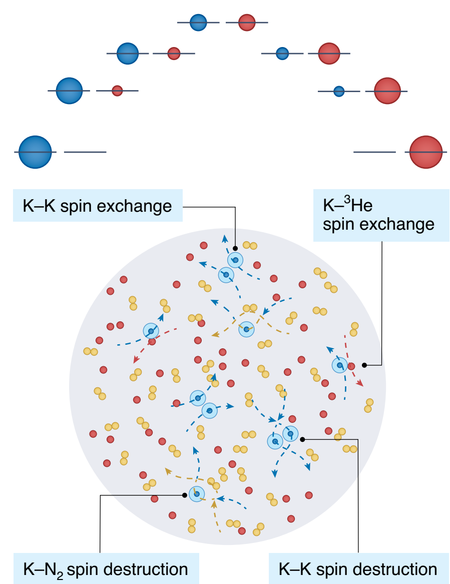

Fig. 1 | Coherent exchange of excitations between helium and potassium collective spins. Two bosonic modes, corresponding to a weak transverse component of the helium and potassium polarized spins, are put into resonance and coherently coupled by spin-exchange collisions. Top: from the left to the right, half a period of the periodic coherent dynamics, where the excitation, initially put in the potassium spin (blue disc), is transferred to the helium nuclear spin (red disk). For each picture of the time sequence, the side-by-side horizontal black lines represent the energy of the two modes. Bottom: different collisional processes in the potassium–helium mixture. The blue (red) circles represent the potassium (helium) atoms, and the buffer gas (nitrogen) is shown in yellow. The dashed lines indicate the trajectories of the atoms. To reach the strong coupling regime, the coherent dynamics has to be faster than the decoherence induced by the spin-destruction collisions. While spin-exchange collisions preserve the total spin, in spin-destruction collisions, some of the spin angular momentum is lost in the rotational angular momentum of the colliding pair.

to bring the two modes into resonance, thanks to the large magnetization of the polarized helium that partially compensates the external field[3]. Once the two systems are set into resonance, the coherent coupling between the alkali and the rare gas spins provided by spin-exchange collisions can efficiently couple the two modes.

In their experiment Shaham and co-workers reached a coherent coupling ten times larger than the remaining relaxation of the alkali atoms by increasing the polarizations and pressures of the two species. This made it possible to observe several oscillations of exchange of excitation between the nuclear and the alkali modes for the first time.

As the authors argue, an efficient coupling between the helium and the alkali spin that is optically accessible could serve as a basis for quantum technologies such as long-lived quantum memories[5] or to generate and retrieve long-lived entanglement between two distant gas cells[6]. Related ideas have also been put forward[7–9] for a different system of pure helium gas where, instead of using an alkali vapour, a fraction of atoms are brought into an optical accessible metastable state. This approach could operate with quite different physical parameters: millibar pressure, room temperature and no buffer gas, avoiding the decoherence induced by collisional processes.

These applications are not immediately within reach, and Shaham and co-workers' results are still in the classical regime. However, they represent an important experimental step towards quantum applications for noble gases. ❐

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Competing interests

The author declares no competing interests.