and accurate, but, unlike other sensors, they do not need to be calibrated against a standard because all atoms of a given type are identical. Atomic sensing of time provides the basis for the Global Positioning System, and sensing of magnetic fields is beginning to have an impact on medicine, archaeology and security. Moreover, atomic sensing of acceleration and gravity is more accurate than any other method[2]. It has long been known that atomic sensitivity can be further enhanced using quantum physics[3,4] — for example, a quantum-logic atomic clock[3] reported in 2010 remains one of the most accurate timekeeping devices.

But electrometry — the measurement of electric fields — has been largely missing from the repertoire of atomic sensors. Different types of electric field, such as those associated with direct or alternating currents, present different challenges for measurement. Measuring constant (direct-current) electric fields is always tricky because the motion of free charges, such as electrons in metals or charges on insulating surfaces in the system through which the field is passing, are hard to remove completely and tend to screen the field.

This is less of a problem for high-frequency alternating-current fields, such as those in the microwave or terahertz region of the electromagnetic spectrum, because the free charges cannot respond to the oscillating field (resonate) quickly enough to screen it. However, atoms tend not to respond to such fields either. Unless, that is, we use an exotic type of atom known as a Rydberg atom, in which the outer electron is excited using a laser such that it is only weakly bound and, on average, spends most of its time far away from the nucleus. Rydberg atoms are highly sensitive to electric fields, especially microwave fields that resonate with a transition between two of the atoms' excited electronic states. In the past few years, this sensitivity has been combined with techniques that allow an optical signal to be produced in response to an electric field, to measure both non-resonant[5] and resonant[6] fields. But until now, all electrometry has depended on essentially classical physical effects.

A remaining challenge was therefore to engineer quantum states to increase the sensitivity of an electrometer. This is addressed in Facon and colleagues' study. Not only do the authors demonstrate quantum engineering, but they also match the sensitivity record for electrometry[6]. Perhaps most surprisingly, the extreme sensitivity of their system is achieved by measuring one atom at a time, whereas previous electrometers[6] relied on measuring many atoms to achieve a comparable performance. The most fascinating part of their work is their use of quantum superposition — a combination of two states that have widely different energy values — to obtain this result.

To understand how quantum superposition can help, consider a sensor in which the number of atoms, N, is increased — the sensitivity goes up because more signal is obtained. But the sensitivity does not rise linearly with N, because the noise that accompanies the signal also increases, with the square root of N. This is because the read-out of an atomic sensor is binary: measurements are made by counting the number of atoms in one of two states, either the ground state or an excited state. Just like counting the number of times we get heads when a coin is tossed N times, the number of events that occur within a given time frame varies, exhibiting a Poisson distribution. These counting statistics limit the precision to what is called the standard quantum limit.

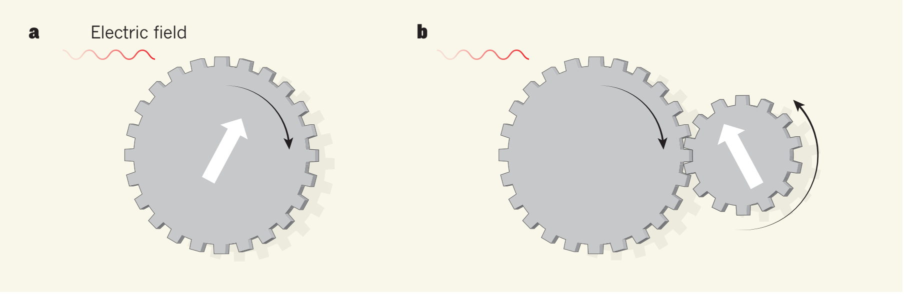

Figure 1 | Quantum effects increase sensitivity in an atomic electrometer. **a**, Electric fields can drive a transition between an electronic ground state and an excited state in atoms. Here, the sloped arrow represents a quantum superposition of excited and ground states for an atom. In a classical atomic electrometer, the electric field can be thought of as driving a wheel that rotates the arrow. The read-out of field strength depends on whether the wheel has rotated to a position at which the arrow is more up than down. The more the wheel rotates for a given electric field, the higher the sensitivity of the device. **b**, Facon *et al.*[1] have used quantum superposition to couple the first wheel to a second one, analogous to mechanical gears. Because the second wheel rotates farther than the first one for a given electric field, the sensitivity of the device is higher than that of the classical electrometer.

The quantum trick to beat this Poissonian noise is to correlate all the atoms in a special way, for example in a quantum superposition known as a Schrödinger cat state. Such a superposition increases the energy gap between the electronic states involved in sensing, thus making the system more sensitive to external perturbation. The enhanced sensitivity is like a gearing system (Fig. 1). In this analogy, the electric field rotates a gear wheel that is coupled to another wheel through quantum superposition; the second wheel rotates faster than the gear wheel, thereby giving a more sensitive read-out. The resulting sensitivity can approach the Heisenberg limit, the maximum sensitivity that can be achieved.

Facon and colleagues use this approach in their electrometer, but rather than using N atoms, they simply use N states in one Rydberg atom. This works because the difference in energy between each adjacent state is the same, like the distance between the rungs of a ladder. The energy difference between the bottom and the Nth rung is therefore the same as the energy difference between having N atoms in the ground state and N atoms on the first rung. The authors used lasers and pulsed electric fields to prepare a Schrödinger cat state that yields an N-fold energy enhancement, and hence the desired N-fold sensitivity improvement for electrometry. Preparing the cat state is the hard part, but the authors are past masters at this, and show that they can easily beat the standard quantum limit for their sensor.

By applying their expertise in quantum felines to electrometry, Facon *et al.* open a new chapter in quantum metrology. Their sensor apparatus is currently rather bulky (metres across) and works only at particular microwave frequencies, but their results impressively demonstrate how cat states enable more-accurate measurements to be made. In addition, their work clearly puts quantum-engineered atomic electrometers right up there with the best atomic clocks and magnetometers. Further work will probably yield devices that exceed the performance of the current best electrometers, and might find applications in quantum radar and astronomy. ■

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CORRECTION

In the News & Views article 'Earth science: An extended yardstick for climate variability' by Nele Meckler (*Nature* **534,** 626–628; 2016), the stalagmites shown in Figure 1 were, in fact, stalactites — the image was upside down. The image in the online article has now been replaced.