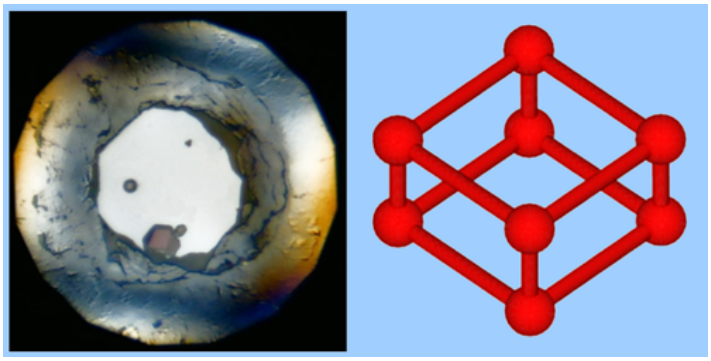
Crushing Oxygen into a Spin Liquid

New evidence supports the idea that solid oxygen switches under pressure to an exotic entangled state.

By **Charles Day**

In gaseous or liquid oxygen, the two unpaired electrons in each O_2 molecule align their spins parallel to each other, turning the molecule into a miniature magnet. When oxygen solidifies, the crystals can adopt various magnetic configurations depending on the temperature and pressure. Now Federico Gorelli of Italy's National Institute of Optics and his collaborators have uncovered evidence that at room temperature and a pressure of 12–18 gigapascals (GPa), solid oxygen harbors a fluctuating state in which electron spins are entangled—a state known in other contexts as a quantum spin liquid [**1**].

Gorelli and his collaborators investigated a phase known as ε oxygen, which consists of vertically oriented molecules arranged horizontally in diamond-shaped "quartets." In 2014, theorists predicted that ε oxygen is split between two phases [**2**]. The higher-pressure ε_0 phase is a conventional diamagnet, a nonmagnetic phase in which the quartets are closer to squares. In the lower-pressure ε_1 phase, the lengths of the quartets' sides are unequal. Crucially, in that state the spins cannot find a single, static configuration. As a result, each quartet hosts a dynamic, disordered arrangement associated with quantum spin liquids [**3**].



Credit: F. Gorelli/INO

Inspired by that prediction, Gorelli and his collaborators used the European Synchrotron Radiation Facility's x-ray beams to determine the lattice parameters of ε oxygen at different pressures. At 18.1 GPa—close to the predicted value of 20 GPa—all of the parameters exhibited a small but finite discontinuity consistent with the predicted ε_1–ε_0 transition. Similarly, indirect signs of quantum spin liquids have been seen in cerium zirconium oxide, ruthenium trichloride, and other materials. But of those putative hosts, ε_1 oxygen is by far the simplest, making the state easier to study.

Charles Day is a Senior Editor for *Physics Magazine*.

REFERENCES

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