Expert insight into current research

# News & views

Condensed-matter physics

## Elite superconductor club has a new member

**Matthias Hepting**

A nickel-based compound has shown evidence of a superconducting state at a temperature of 80 kelvin. The material bridges a gap between other nickelates and a notable class of superconductor containing copper. **See p.493**

Superconductivity is a quantum mechanical phenomenon wherein electrons in a material form pairs and condense into a state that leads to the disappearance of the material's electrical resistance. On page 493, Sun *et al.*[1] report that a nickel-based compound becomes superconducting at around 80 kelvin when subjected to a pressure equivalent to the force that 120 elephants would exert on the area of a postage stamp. The material seems to straddle two separate classes of superconductor – blowing open the search for superconducting materials that could prove technologically useful.

Polycrystalline powders of $La_3Ni_2O_7$ (La, lanthanum; Ni, nickel; O, oxygen) were synthesized nearly 30 years ago[2], and the material's electrical properties have been extensively characterized – even under pressures as high as 18.5 gigapascals (1 GPa is $10^9$ Pa) – but there were previously no real hints of superconductivity[3]. The game changer came last year, when members of the same group as Sun and colleagues synthesized the first single crystals of $La_3Ni_2O_7$ (ref. 4). Sun *et al.* now report the results of their own high-pressure study, conducted at 14 GPa, in which the unforeseen superconducting properties materialized. The discovery marks a crucial milestone in the quest for materials with an elevated superconducting transition temperature ($T_c$).

Research on superconductors started in 1911 with the pivotal observation that mercury loses its electrical resistance when cooled to about 4 K, the frigid temperature below which helium liquefies[5]. Hot on the heels of this initial revelation came the discovery of other elemental superconductors, including lead with a $T_c$ of 7.2 K, niobium at 9.2 K and, later, a niobium–germanium alloy, with superconductivity at temperatures nearing 23 K. But these temperatures were too low to be of immediate practical use, and the search for materials with higher $T_c$ values – ideally approaching room temperature – reached an impasse over the next few decades. During this period, the development of a rigorous theoretical framework identified the coupling between electrons and crystal lattice vibrations (phonons) as the microscopic mechanism driving superconductivity.

Fast forward to the 1980s, when the discovery of cuprate superconductors reshaped the landscape of research in condensed-matter physics. These ceramic compounds, consisting of layers of copper and oxygen, show superconductivity at temperatures that had previously been considered unreachable[6]. Specifically, a cuprate containing yttrium, barium, copper and oxygen boasts a $T_c$ of 92 K, which is well above the point at which nitrogen liquefies (77 K). The record for cuprates is 133 K, set by a mercury-based compound, and this temperature can be increased further under the application of pressure[7].

Under even greater pressures, repeated experiments on compounds containing hydrogen (H), such as $LaH_{10}$, have shown $T_c$ values of around 250 K (ref. 8). Yet the mechanism in these 'superhydrides' is probably based on conventional electron–phonon coupling. By contrast, the physics underpinning the superconductivity in cuprates seems to be unconventional, and a comprehensive understanding of the underlying mechanism has remained unknown[6].

In the late 2000s, the spotlight shifted to iron-based superconductors[9], including layered iron pnictides that could reach a $T_c$ of up to 56 K at ambient pressures. These compounds introduced renewed vigour to the domain of unconventional superconductors, in part because of their similarity to cuprates – both materials show magnetic and charge instabilities near the transition to superconductivity.

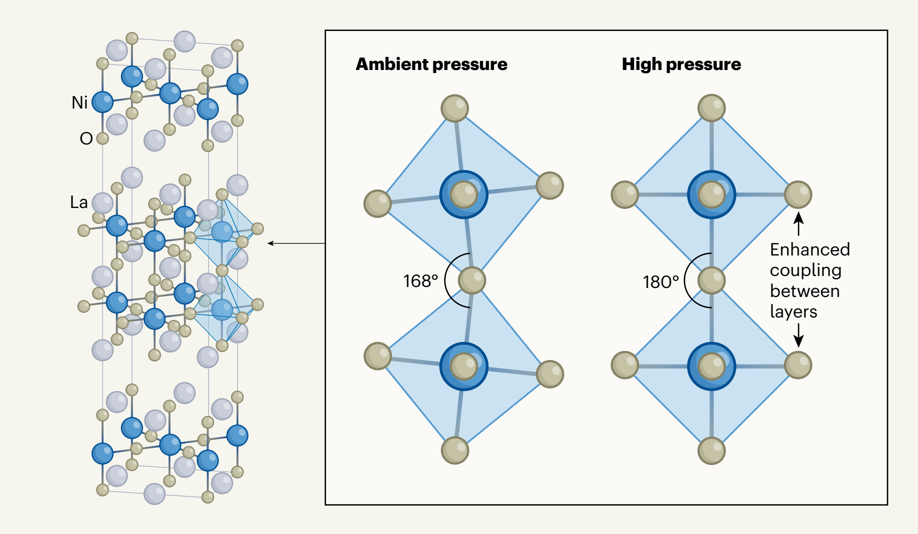

**Figure 1 | A new superconductor under pressure.** Superconductivity is a state in which a material's electrical resistance disappears. Sun *et al.*[1] detected superconducting behaviour in the nickel-based compound $La_3Ni_2O_7$ (La, lanthanum; Ni, nickel; O, oxygen) under high pressure and at the relatively high temperature of 80 kelvin. This brings it into the temperature domain of copper-based superconductors called cuprates, and distinguishes it from other nickelates, which exhibit superconductivity at much lower temperatures. The structure of $La_3Ni_2O_7$ is characterized by stacks of bilayers containing nickel and oxygen octahedra. A reorientation of these octahedra under high pressure enhances the coupling between the layers, potentially giving rise to electronic states similar to those of cuprates.

Indeed, magnetic fluctuations are thought to be involved in mediating electron pairing in cuprates[6], and such a mechanism might be a recurring theme among unconventional superconductors.

In support of this idea, the 2019 discovery[10] of superconductivity in the nickel-based compound $Nd_{0.8}Sr_{0.2}NiO_2$ (Nd, neodymium; Sr, strontium) garnered considerable interest. The crystal structure of this material is said to be infinitely layered, because it consists of a periodic repetition of planes of nickel and oxygen, mirroring the building blocks in the structure of cuprates. The magnetic fluctuations in the material are also reminiscent of those in cuprates. Yet there are clear distinctions between superconductors containing copper, iron and nickel[11]. And with a relatively modest $T_c$ of about 20 K, the infinite-layer nickelates do not qualify as high-temperature superconductors, although pressure can enhance their $T_c$ to around 31 K (ref. 12).

In light of this, Sun and co-workers' report of a $T_c$ of 80 K in $La_3Ni_2O_7$ stands out – the material seems to be edging into the realm of cuprates, with unconventional superconductivity above the 77 K benchmark set by the point at which nitrogen liquefies. Moreover, $La_3Ni_2O_7$ comprises bilayers of nickel and oxygen arranged in octahedra (Fig. 1). This structure is noteworthy because it differs from that of the infinite-layer nickelate superconductors, which closely resembles the structure of cuprates.

Sun and colleagues' calculations reveal that coupling between the double layers is enhanced by a pressure-induced reorientation of the octahedral geometry, which could give rise to electronic states similar to those of cuprates. Whether $La_3Ni_2O_7$ indeed features cuprate-like electronic states, with a similar pairing mechanism, remains a tantalizing question for complementary theoretical studies. Either way, it is worth noting that $La_3Ni_2O_7$ shows magnetic and charge instabilities[4], which are suppressed with the onset of superconductivity. This suggests once more a theme among unconventional superconductors.

In future experimental investigations, it will be crucial to address the sample-to-sample variation reported by the authors, who found that certain single crystals lacked a superconducting transition. This discrepancy might be related to potential variations in the oxygen content of $La_3Ni_2O_7$, and could also shed light on the origin of the absence of superconductivity in previously studied powder samples[2,3].

The discovery of superconductivity in $La_3Ni_2O_7$ markedly diversifies the landscape of high-temperature superconductors. Exploring other multilayer nickelates similar to the bilayer compound $La_3Ni_2O_7$ offers an exciting prospect for uncovering new superconductors, perhaps even with a $T_c$ surpassing 80 K. This would initiate a serious challenge to the current dominance of cuprates in research on superconductors.

**Matthias Hepting** is in the Solid State Spectroscopy Department, Max Planck Institute for Solid State Research, 70569 Stuttgart, Germany.
e-mail: hepting@fkf.mpg.de

1. Sun, H. *et al. Nature* **621**, 493–498 (2023).
2. Zhang, Z., Greenblatt, M. & Goodenough, J. B. *J. Solid State Chem.* **108**, 402–409 (1994).
3. Hosoya, T. *et al. J. Phys. Conf. Ser.* **121**, 052013 (2008).
4. Liu, Z. *et al. Sci. China Phys. Mech. Astron.* **66**, 217411 (2023).
5. Buckel, W. & Kleiner, R. *Superconductivity: Fundamentals and Applications* 2nd edn (Wiley, 2004).
6. Keimer, B. *et al. Nature* **518**, 179–186 (2015).
7. Gao, L. *et al. Phys. Rev. B* **50**, 4260–4263 (1994).
8. Eremets, M. I. *et al. J. Supercond. Nov. Magn.* **35**, 965–977 (2022).
9. Fernandes, R. F. *et al. Nature* **601**, 35–44 (2022).
10. Li, D. *et al. Nature* **527**, 624–627 (2019).
11. Gu, Q. *et al. Nature Commun.* **11**, 6027 (2020).
12. Wang, N. N. *et al. Nature Commun.* **13**, 4367 (2022).

**The author declares no competing interests.**

Medical research

# Immune treatment tackles a lung disease in smokers

**John V. Fahy & Richard M. Locksley**

Smoking causes chronic obstructive pulmonary disease. Some people with this disease have high levels of eosinophil cells, which is typical of the type 2 category of inflammation, and blocking such inflammation improves their lung health.

Chronic obstructive pulmonary disease (COPD) is a common lung disease caused by tobacco smoke and other airborne pollutants, and it can be fatal. COPD exacerbations – defined as acute difficulties in breathing – can be triggered by viral or bacterial infections, or by changes in air quality[1]. Exacerbations are associated with diminished lung function, which can lead to respiratory failure. This increases the risk of death and requires treatment in hospital. Because chronic lung inflammation in COPD persists between exacerbations and even after cessation of smoking, a major goal is to reduce persistent inflammation to decrease the frequency and severity of exacerbations.

Writing in the *New England Journal of Medicine*, Bhatt *et al.*[2] report the results of a clinical trial for COPD that tested an antibody called dupilumab. The antibody broadly blocks a category of inflammation (type 2) that is associated with high numbers of white blood cells called eosinophils. The authors found that treatment with dupilumab decreased the rate of exacerbations and improved lung function in a subset of individuals with COPD who had high numbers of eosinophil in their blood.

Inflammation occurs when groupings of key molecules called cytokines and chemokines are secreted by immune cells to communicate with other cells and orchestrate the resulting immune response. Inflammation is divided into three categories: chronic or type 1 inflammation (associated with the cytokine IFN-γ); allergic or type 2 inflammation (associated with the cytokines IL-4, IL-5 and IL-13); and acute or type 3 inflammation (associated with the cytokine IL-17). Knowledge of these distinct immune responses has guided the use of anti-cytokine interventions in precision-medicine approaches to treat diseases associated with inflammation[3]. IL-4 and IL-13 are produced by subsets of immune cells, and dupilumab blocks the receptor required for signalling by these molecules (Fig. 1).

Bhatt and colleagues' dupilumab trial for COPD was prompted by the success of cytokine-targeting antibodies that block type 2 inflammation in people who have asthma[4]. Between 20% and 25% of people with COPD have higher-than-normal numbers of eosinophils, which is often associated with type 2 inflammation and is a potential risk factor for COPD exacerbations[5]. The authors tested whether dupilumab decreases exacerbations in this particular subset of individuals.

Examining data for almost 1,000 individuals who had COPD with high levels of blood eosinophils, the authors found that dupilumab lowered the annualized rate of moderate or severe exacerbations by nearly one-third and improved lung function and quality of life compared with those who did not receive the antibody. This result is important because current treatments for people with COPD have limited efficacy, and improved therapies could decrease the personal and economic costs of COPD exacerbations.

Besides dupilumab, other cytokine-targeting antibodies that are effective in