

Elementary, my dear physicists!

Charles Day

“It is an old maxim of mine that when you have excluded the impossible, whatever remains, however improbable, must be the truth.”

Spoken by Sherlock Holmes, that line appears in “The Adventure of the Beryl Coronet.” The short story by Holmes’s creator, Arthur Conan Doyle, first appeared in the *Strand Magazine* in 1892. But my first encounter with the quotation was in a 2005 paper by Igor Mazin and Michelle Johannes entitled “A critical assessment of the superconducting pairing symmetry in $\text{Na}_x\text{CoO}_2 \cdot y\text{H}_2\text{O}$.”¹

The symmetry of the title belongs to the Cooper pairs of electrons that underlie sodium cobaltate’s superconductivity. With a modest T_c of no more than 5 K, the state exists only when water molecules are intercalated between the compound’s sodium atoms and cobaltate layers. Cooper pairs are composite bosons whose total spin S is an integer. When pairing up, spin- $\frac{1}{2}$ electrons have two choices for S , 0 and 1. They are also constrained, as a pair of fermions, to have an antisymmetric wavefunction. Fixing S , therefore, fixes the pair’s total orbital angular momentum L : If $S = 0$, L must be an even integer; if $S = 1$, L must be an odd integer.

How electrons satisfy those constraints to form pairs depends on the symmetry of the lattice and on what fluctuations polarize the electrons and nudge them together. The superconductivity of $\text{Na}_x\text{CoO}_2 \cdot y\text{H}_2\text{O}$ intrigues physicists because the CoO_2 layers have hexagonal symmetry unlike the CuO_2 layers of the high- T_c cuprates, which have square symmetry.

Kazunori Takada and his colleagues reported their discovery of the superconductivity of $\text{Na}_x\text{CoO}_2 \cdot y\text{H}_2\text{O}$ in 2003.² Two years later when Mazin and Johannes wrote their Holmes-quoting paper, more experiments had been conducted on the compound and more explanations for its superconductivity had been proposed. In their paper, Mazin and Johannes set out to deduce which of 25 possible pairing symmetries was the most consistent with the strongest evidence. They eliminated all but two suspects, both of which are f wave—that is, $L = 3$. “ $\text{Na}_x\text{CoO}_2 \cdot y\text{H}_2\text{O}$ may be the most exotic superconductor discovered so far,” they wrote.

According to Guinness World Records, Sherlock Holmes is the most portrayed literary character in the history of theater, film, and television. Among recent adaptations is *Sherlock*, a BBC TV series that ran for four three-part seasons in 2010–17,



starred Benedict Cumberbatch as Holmes, and took place in present-day London.

In the first episode of the series, “A Study in Pink,” Holmes examines the worn-looking wedding ring of a dead woman. “Ten years old at least,” he tells a forensic examiner. “State of her marriage right there. . . . The only polishing it gets is when she works it off her finger.” The woman, Holmes deduces, has had a string of extramarital affairs.

My wedding ring is 27 years old. Its inside is shiny because I’ve removed it over the years for rowing, swimming, and cooking. Its outside is dull and scratched because I like its evident age to connote the length of my happy marriage.

The fictional Holmes does not consider plausible alternatives to his theories lest they undermine his evident brilliance. Nonfictional physicists, however, have to weigh alternative explanations. What’s more, they have to consider the possibility that their data are uncertain or even spurious.

Until I read that yet another Holmes adaptation, the movie *Enola Holmes*, would be getting a sequel, I had forgotten about $\text{Na}_x\text{CoO}_2 \cdot y\text{H}_2\text{O}$. A search for the latest research on the topic yielded a paper from this past May by Niklas Witt and his collaborators.³ The researchers used a numerical approach called FLEX-IR and applied it to the compound to explore its electronic properties. Like Mazin and Johannes before them, they concluded the pairing is f wave, although they favored the other of Mazin and Johannes’s two suspects. A definitive answer, the two groups agreed, would come from further experiments.

Whether those experiments will be performed is not clear. Research in $\text{Na}_x\text{CoO}_2 \cdot y\text{H}_2\text{O}$ has become “unfashionable,” Mazin told me in an email. That fate befalls a problem, he continued, “either because people believe it’s solved or because solving it is so hard and too unprofitable.” Neither possibility afflicted Sherlock Holmes.

References

1. I. I. Mazin, M. D. Johannes, *Nat. Phys.* **1**, 91 (2005).
2. K. Takada et al., *Nature* **422**, 53 (2003).
3. N. Witt et al., *Phys. Rev. B* **103**, 205148 (2021).

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