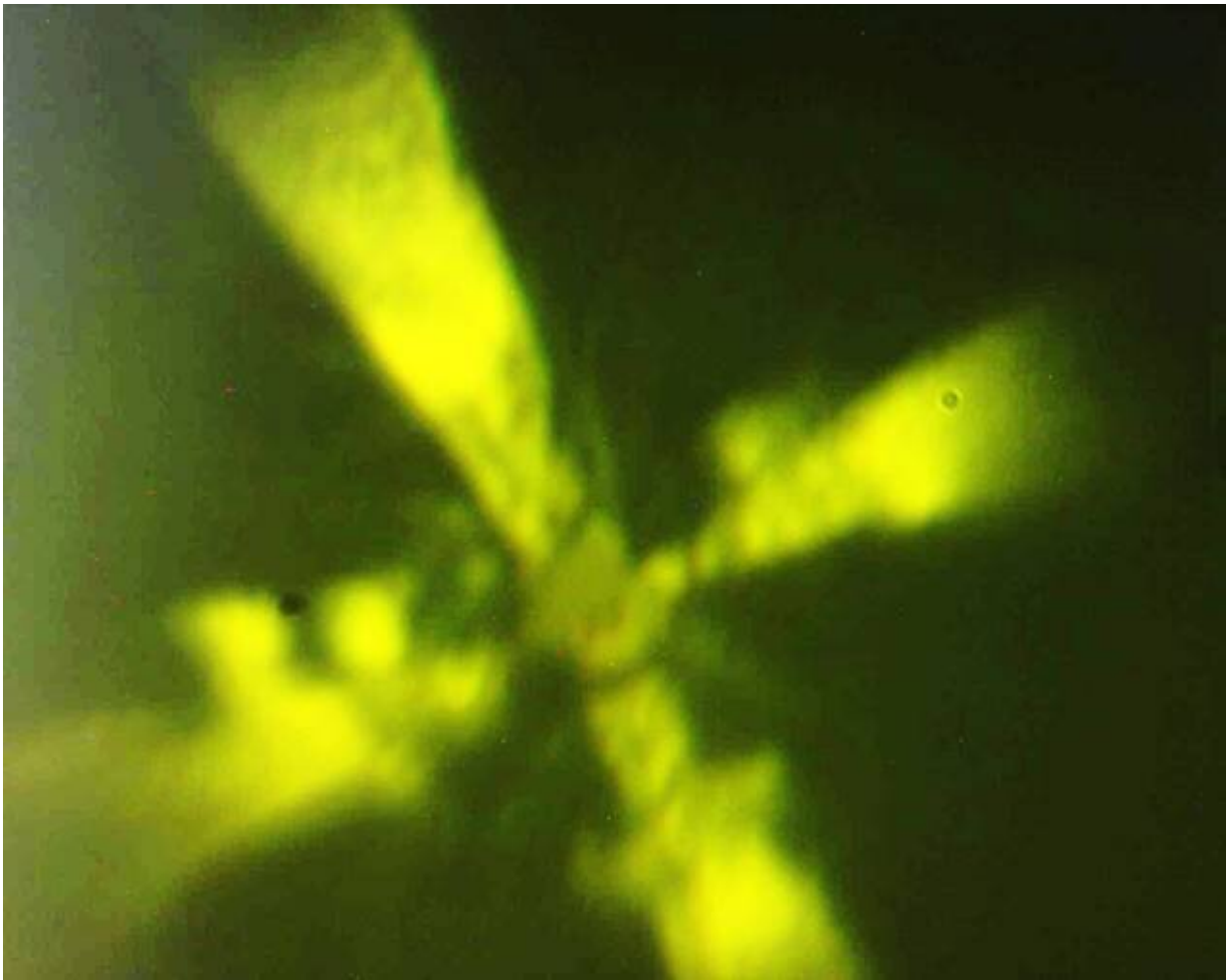


Molecular hydrogen becomes semimetallic at pressures above 350 GPa

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Credit: Eremets et al.

According to condensed matter physics predictions, at a high enough pressure, hydrogen should dissociate and transform into an atomic metal. However, the exact pressure range at which this occurs has not yet been ascertained, and the process through which hydrogen becomes a metal is still somewhat unclear.

In a recent study, researchers at the Max Planck Institute of Chemistry demonstrated that at a pressure of 350-360 GPa and at temperatures below 200K, molecular [hydrogen](#) starts to conduct and becomes semimetallic. Their paper, published in *Nature Physics*, provides interesting new insight about the transition of hydrogen at high pressures, unveiling some of the properties it acquires.

"Typically, metallic hydrogen is considered to be atomic hydrogen—a crystal built from protons after dissociation of the molecules," Mikhail Erements, one of the researchers who carried out the study, told Phys.org. "However, hydrogen can also transform into a metal in the molecular state—in this case, electronic bands of molecular hydrogen crystal broaden and eventually overlap so that the band gap closes, free electrons and holes appear—this is metallic state."

The initial state in which the electronic bands of [molecular hydrogen](#) crystal overlap is known as semimetal. In this state, the metal has poor conductivity, as the number of carriers is low. If the pressure is increased further, however, this poorly conducting metal turns into a normal metal and eventually into atomic hydrogen.

"Our objective was to find the pressure at which metallic electrical conductivity appears, and if this results in a molecular or atomic metal," Erements said. "We thus performed [electrical measurements](#), as this is the only method that directly tells us whether hydrogen conducts and if it is a metal. A metal typically conducts to the lowest temperatures; a semiconductor can also conduct, but at lower temperatures, conductivity

exponentially decreases and disappears."

In their experiments, the researchers gathered Raman measurements up to 480 GPa to identify changes that take place in hydrogen at different pressures. They found that hydrogen started to conduct at pressures above 360 GPa, but it remained a semimetal up until 440 GPa.

To collect Raman measurements, the researchers used small DACs with synthetic diamonds. These diamonds have extremely low luminescence even at pressures of ~500 GPa. For electrical measurements, on the other hand, they used four electrical leads sputtered on diamond anvils, which were isolated from the metallic gasket by an insulating layer.

Overall, the measurements they collected showed that the semimetallic hydrogen observed in their experiments is in the molecular state. These findings thus confirm their hypothesis that hydrogen becomes a metal in its molecular state.

"Above 360 GPa, electrical conductivity strongly increased with pressure," Erements explained. "The conductivity did not decrease exponentially with cooling, indicating that hydrogen is not a semiconductor. On the other hand, it is not a good metal, as the conductivity only slightly increases with cooling. Such behavior is typical for semimetals such as bismuth or pressure-induced semimetals such as oxygen or xenon."

Overall, the measurements collected by Erements and his colleagues provide evidence that semimetallic hydrogen remains in the molecular state at least up to a pressure of 440 GPa. When the pressure rises above 440 GPa, however, the Raman signal emitted by the hydrogen disappears, which suggests that a further transformation is taking place.

"The achievement of the required pressures above 350 GPa is a difficult

task," Eremets said. "It depends on a number of factors, first, of the geometry of the anvils. We performed many attempts to reach the multimegabar pressures. However, we obtained reproducible data."

The recent study carried out by Eremets and his colleagues clearly demonstrates that above ~360 GPa, hydrogen turns into a semimetal in its molecular state. However, this semimetallic substance presents some unusual behavior, which is not aligned with common theoretical predictions of metallic hydrogen being in an atomic state. On the contrary, the researchers observed that hydrogen shifts into a semimetallic substance in its molecular state.

"Our findings should stimulate further theoretical and experimental works on the understanding of the complex transformation of hydrogen to [metal](#)," Eremets said. "We are now planning to extend our electrical measurements to higher pressures and find superconductivity in [metallic hydrogen](#)."

More information: M. I. Eremets et al. Semimetallic molecular hydrogen at pressure above 350 GPa, *Nature Physics* (2019). [DOI: 10.1038/s41567-019-0646-x](https://doi.org/10.1038/s41567-019-0646-x)

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