Study suggests helium plays a 'nanny' role in forming stable chemical compounds under high pressure

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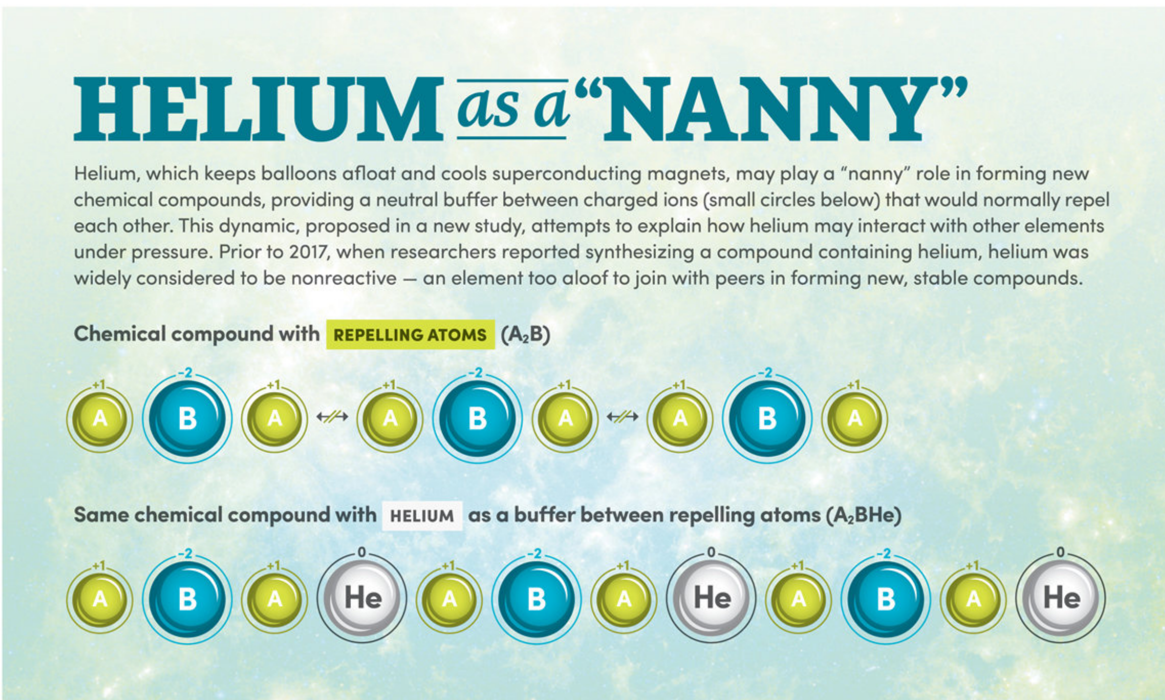

Credit: Bob Wilder/ University at Buffalo

Helium, the second lightest element in the universe, has a variety of uses, from keeping balloons afloat to cooling superconducting magnets.

It is also a noble gas—so labeled because it was long believed to be "too aloof" to react with the other elements on the periodic table.

Now, however, a team of scientists led by California State University, Northridge (CSUN) chemistry professor Maosheng Miao, and including University at Buffalo chemistry professor Eva Zurek, has provided a theoretical explanation of how helium may be capable of forming stable solid compounds—the myriad combinations of chemical elements that create all kinds of materials.

The research also suggests that the gas—whose supply on Earth has been decreasing—may be found in the Earth's mantle, a place once considered unlikely since there was no known chemistry to keep helium there.

The new study, "Reactivity of He with ionic compounds under high pressure," was published on March 5 in *Nature Communications*. The work was inspired by a 2017 study in which a different research team reported synthesizing a stable compound from helium and sodium, an element in table salt, under high pressure.

Though that reaction was proven by experiments, Miao said, "we did not understand why it could happen. Now we do. Helium is a good 'nanny.'"

"We propose that there is a general driving force for helium to react with ionic compounds as soon as these compounds have unequal numbers of negatively charged and positively charged ions," said Miao, Ph.D. "As a result, it stabilizes what would normally be an unstable situation, sort of the way a nanny mediates when your kids don't get along."

"The research is fundamentally interesting because helium was always considered to be unreactive—the element that doesn't react with anything," said study co-author Zurek, Ph.D., a chemistry professor in the UB College of Arts and Sciences. "Our research illustrates a new mechanism for why helium might react with other chemical species to form compounds under pressure. Moreover, we predicted new sets of compounds that might also react with helium under pressure that were not studied in the original work."

In addition to Miao and Zurek, the team included visiting scholars Zhen Liu and Jorge Botana of CSUN (postdocs in the Beijing Computational Science Research Center in China); physics professor Andreas Hermann, Ph.D., of the University of Edinburgh in the United Kingdom; CSUN chemistry undergraduate Steven Valdez; physics professor Dadong Yan, Ph.D., of Beijing Normal University in China; and physics professor Hai-qing Lin, Ph.D., director of the Beijing Computational Science Research Center.

Helium's 'nanny' role

Ions are atoms or molecules with an electric charge. In some stable chemical compounds, one negatively charged ion balances out one positively charged ion. (An example of this is table salt, made up of positively charged sodium and negatively charged chlorine ions).

But when compounds contain unequal numbers of negatively and positively charged ions, repulsion between atoms with the same charge may drive the structure to become unstable under pressure.

That's where helium comes in. "It's sort of like the nanny," Miao said.

"The chemical elements join together to form a compound, sort of like a family," he explained. "But, like in any family, not everyone gets along—in this case because you either have too many negative or positive ions.

"Now, we're going to apply pressure to make this compound work, which is like putting this family, this compound, into a very small car," Miao continued. "You know what happens when you force your kids to sit together in the back seat of a small car, sometimes they don't get along—there's bickering and pushing. Well, helium is the nanny in this chemical compound's car. It sits between the kids to help them get along, but it really isn't part of the family."

In the case of chemical compounds, Miao explained, helium doesn't form any kind of chemical bond with its neighboring atoms. Instead, it inserts itself between the compound's elements to keep them stable.

The new research lays the groundwork for future study of helium compounds by predicting additional compounds that would be stable under pressure, such as a compound consisting of magnesium fluoride and a helium atom, and another consisting of calcium fluoride and a helium atom.

More helium on Earth?

Helium's lightness and extensive use mean the Earth's supply of the element is slowly being depleted.

Miao said if his team's theory proves true—"I believe it will, and it has been partially proven"—it could not only provide new insights into the role helium plays in chemical compounds, but also provide clues to where more of it can be found.

"Our work reveals that helium has the propensity to react with a broad range of ionic compounds at even low pressures, which implies that there might be much more of it in the Earth than we realize," he said. "Since most of the Earth's minerals contain unequal numbers of positively and negatively charged ions, our work suggests that large quantities of helium might be stored in the Earth's mantle."

More information: Xiao Dong et al. A stable compound of helium and sodium at high pressure, *Nature Chemistry* (2017). DOI: 10.1038/nchem.2716

Zhen Liu et al. Reactivity of He with ionic compounds under high pressure, *Nature Communications* (2018). DOI: 10.1038/s41467-018-03284-y

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