

METALLIC SUPERHEROES THAT TRAP POISONOUS ARSENIC FROM WATER

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YOUNG REVIEWERS:



AKSHARA

AGE: 13



ALI

AGE: 13



BILAL

AGE: 15

Water pollution is a very concerning problem since it affects millions of people around the world. Arsenic is a highly toxic metal that can cause serious health problems if consumed. Substances called metal oxides can help to remove contaminants like arsenic from water, and researchers have recently shown that these superheroes are even more powerful when they are combined. In anime, the superheroes Goku and Vegeta can fuse to become Gogeta, and when they do so their power increases. Similarly, combining metal oxides is a superpower that could save the world from poisonous arsenic, through a trapping mechanism called adsorption. In this article, we will explain what arsenic is, how it can affect humans, and how metal oxides might eventually help us to produce safer water.

WATER: IMPORTANT FOR ALL LIVING THINGS

Water is one of the most important natural resources. It is critical for the survival of living beings and for the development of societies. However, water is not equally distributed across the world—some

AQUIFERS

Water reservoirs located below the Earth's surface, where water circulates through cracks in rocks.

regions are extremely humid and others are very dry. In addition, the demand for water has increased as the human population has grown. To meet the growing need, technology has been used to extract water from much deeper **aquifers**. However, this water often contains high concentrations of substances such as arsenic from the rocks surrounding the aquifers, which make it undrinkable. At the same time, human activities have also contributed to contamination of water with elements such as arsenic, mercury, cadmium, chromium, and lead. Among these elements, arsenic appears to be the most toxic to humans and other animals [1].

WHAT IS ARSENIC AND HOW DOES IT AFFECT HUMANS?

Arsenic is a natural element of the Earth's crust, and it is found in the air, water, and soil. Arsenic can exist in two forms: organic and inorganic. Inorganic arsenic compounds found in water are highly toxic, while the organic compounds are less toxic and are found in fish and shellfish. Exposure to high levels of inorganic arsenic usually happens through drinking contaminated water or the use of contaminated water for food preparation and irrigation of food crops. Human exposure to arsenic has become a major global concern.

Long-term ingestion of arsenic-contaminated water, even in very low amounts, can pose health risks (Figure 1) [2]. According to the World Health Organization (WHO), exposure to low amounts of arsenic over ~5 years can cause skin pigmentation changes, skin lesions, and thick calluses on the palms of the hands and soles of the feet. In addition, arsenic can cause skin, bladder, and lung cancer. The WHO recommends limiting inorganic arsenic to 10 micrograms per liter ($\mu\text{g/L}$) of water for human consumption. Natural contamination of groundwater with arsenic has been reported worldwide, with concentrations well above the maximum permissible limit. Arsenic concentrations of up to 25 $\mu\text{g/L}$ have been reported in groundwater in parts of Mexico [3]. In other countries, such as Bolivia, Bangladesh, Cambodia, Taiwan, Pakistan, Thailand, and Vietnam, arsenic concentrations of 45.9, 4,600, 178, 1,800, 2,580, 5,000 and 159 $\mu\text{g/L}$, respectively, have been found in groundwater [3].

METAL OXIDES: HEROES TO THE RESCUE

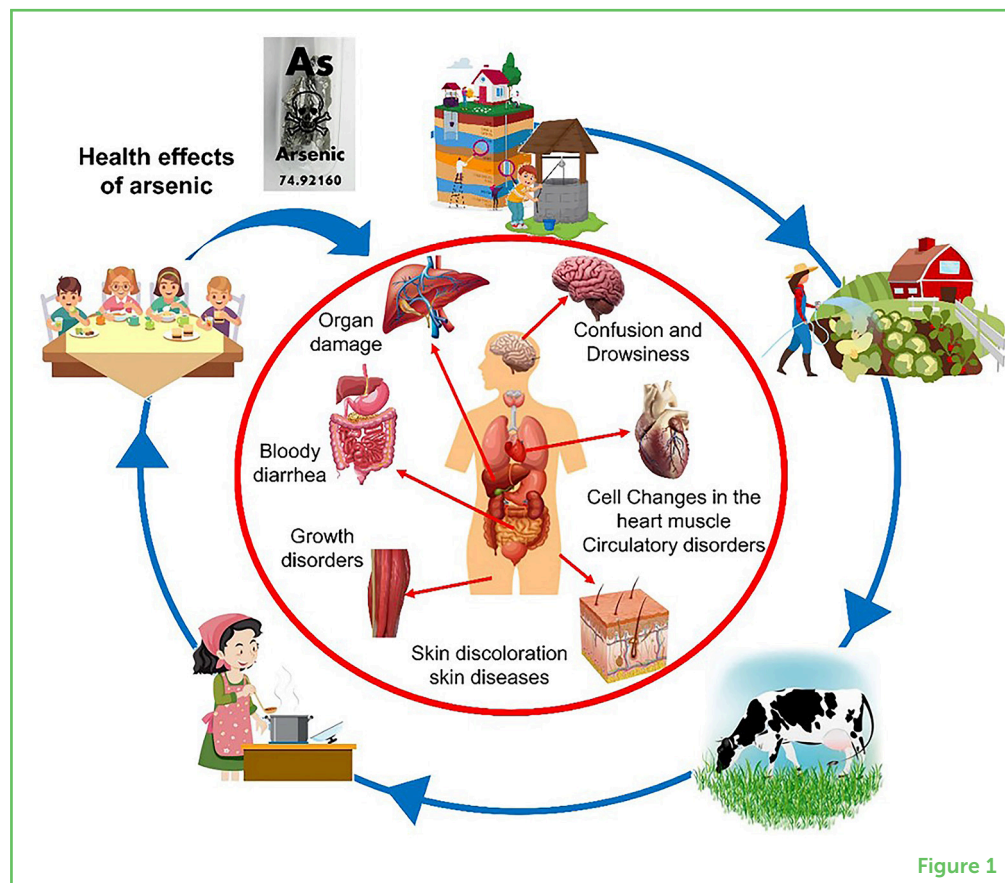
Metal oxides are compounds that result from the combination of a metal with a non-metal, such as oxygen. The reddish, powdery rust you may have seen on a metal object left outdoors is an example of a metal oxide. When metal oxides are placed in water, their surfaces can stick to contaminants that have a negative charge, like arsenic. This quality is interesting to researchers because it means that metal oxides may be able to purify water by removing contaminants. For example,

METAL OXIDE

Combination of a metal (such as Ce or Fe) with oxygen.

Figure 1

The main way that arsenic gets into humans is through water contaminated with arsenic. The use of arsenic-contaminated water to irrigate crops, prepare food, and as drinking water for animals and humans can cause serious health problems and even cancer.



metallic oxides of cerium (CeO_x) and iron (FeO_x) have been shown to be very good at removing arsenic from water.

If you are familiar with Dragon Ball anime, you could imagine that Goku is CeO_x and Vegeta is FeO_x . Both oxides have the power to capture various contaminants from water, including arsenic, the same way that Goku and Vegeta have the power to defeat the evildoers who threaten the wellbeing of the Earth. You may remember that Goku learns a technique known as the Fusion Dance, which can unite two bodies into a single being. Similarly, in recent years there has been a special interest in combining metallic oxides for the removal of arsenic from water. This is because these **bimetallic oxides** are *even better* at removing contaminants from water than either oxide is on its own [4]. In other words, the metallic oxides CeO_x and FeO_x increase their arsenic-capture power by merging to create $\text{CeO}_x:\text{FeO}_x$, which is similar to Goku and Vegeta who, by merging to become Gogeta, increase their powers to defeat the evil ones who threaten Earth. To achieve this, Goku and Vegeta must perfectly align their fingers, and the positions of their legs and arms must have the same angle (Figure 2A).

To create bimetallic oxides, it is important for researchers to determine the optimal parameters, such as temperature, pressure, and concentration of each metal oxide (Figure 2B).

BIMETALLIC OXIDE

Combination of two different metals (such as Ce and Fe) with oxygen.

Figure 2

(A) Goku and Vegeta fuse to become Gogeta by aligning their fingers and the angles of their arms and legs. (B) In a similar way, the bimetallic oxide $\text{CeO}_x:\text{FeO}_x$ is formed when the optimal temperature, pressure, and concentrations of cerium and iron oxide are present. (C) SEM images of CeO_x , FeO_x , and the bimetallic oxide $\text{CeO}_x:\text{FeO}_x$ (Dragon Ball images are property of Akira Toriyama).

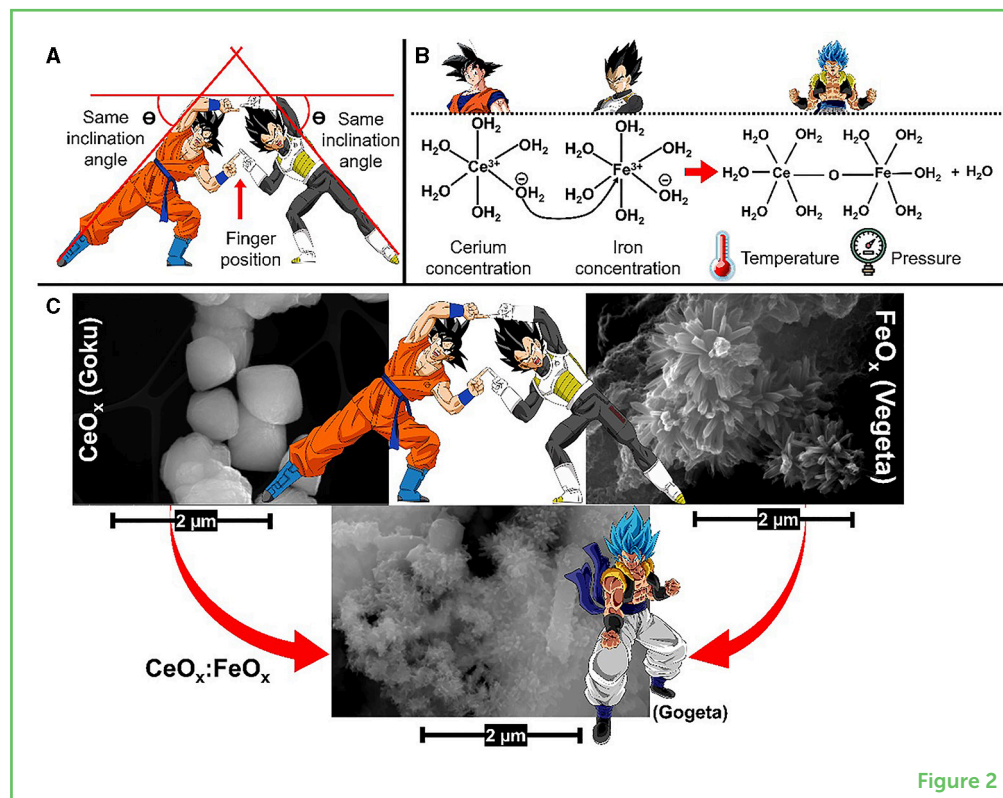


Figure 2

Figure 2C shows the structure of these materials seen using **scanning electron microscopy** (SEM). Cerium oxides (CeO_x) have an octahedral (eight-sided) structure and iron oxides (FeO_x) appear as flower-shaped structures. However, the bimetallic oxide ($\text{CeO}_x:\text{FeO}_x$) has a completely different structure that looks like a bunch of tiny needles sticking together in cloud-like shapes [5]. The SEM micrograph of $\text{CeO}_x:\text{FeO}_x$ (Gogeta) shows many tiny branches, providing lots of **surface area** for arsenic to stick to.

HOW DO BIMETALLIC OXIDES REMOVE ARSENIC FROM WATER?

Broly is a very powerful villain and, even when he was just a baby, his immense power caused fear in those around him. Similar to Broly, arsenic is dangerous because it can cause severe damage to humans even at very low concentrations. Therefore, Goku (CeO_x) and Vegeta (FeO_x) join forces to defeat the powerful villain Broly (arsenic). Bimetallic oxides remove arsenic through a process called **adsorption**. Adsorption is process in which one or more substances present in a fluid (liquid or gas) accumulate on a surface and are thus removed from the fluid. Basically, pieces of the bimetallic oxide molecules are replaced by arsenic, through a reaction called **ligand exchange** (Figure 3). Once the arsenic binds to the bimetallic oxide, it is removed from the water and water molecules are formed by the reaction [5].

SCANNING ELECTRON MICROSCOPY

A widely used technique for examining and analyzing extremely tiny objects that cannot be seen with a "regular" light microscope.

SURFACE AREA

The total area of a solid material, including the area within any pores.

ADSORPTION

When molecules, ions, or compounds in a solution stick to the surface of a solid material.

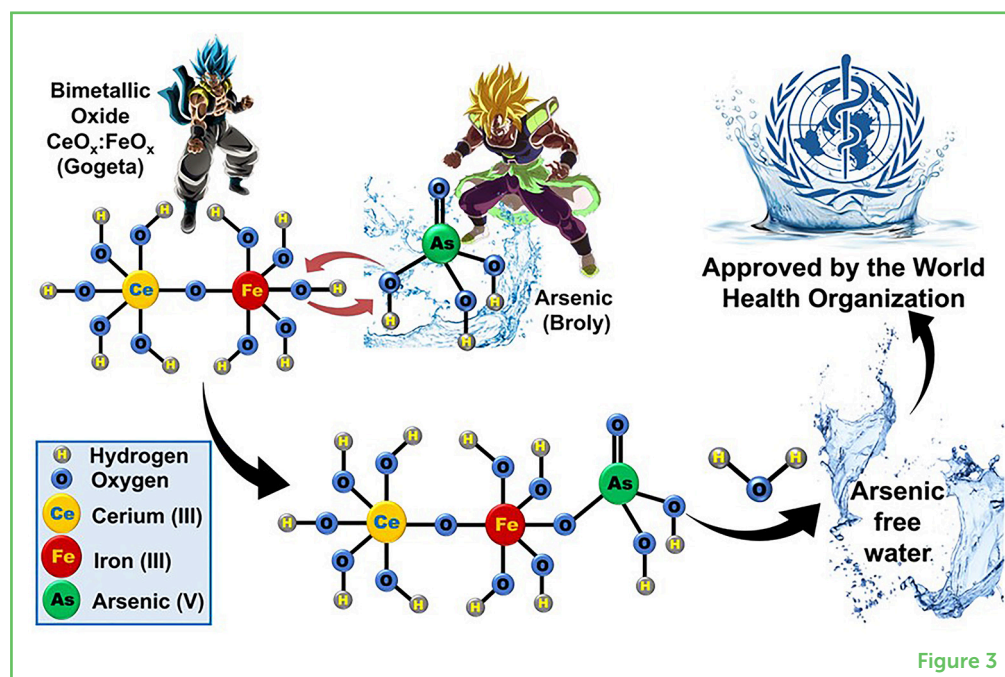
LIGAND EXCHANGE

When a molecule exchanges part of itself with another molecule, to form a new compound or molecule.

This produces arsenic-free water that complies with the maximum limit of 10 $\mu\text{g/L}$ recommended by the WHO.

Figure 3

Just as Gogeta can defeat the evil villain Broly, the bimetallic oxide $\text{CeO}_x:\text{FeO}_x$ can bind to arsenic and remove it from water. Water is also produced in that reaction. The levels of arsenic in the purified water are within the limits recommended by the World Health Organization (Dragon Ball images are property of Akira Toriyama).



HOW WILL BIMETALLIC OXIDES BE USED IN WATER PURIFICATION?

Scientific advances in the synthesis of adsorbent materials, such as $\text{CeO}_x:\text{FeO}_x$ not only solve an environmental problem (arsenic contamination of aquifers) but also prevent the poisoning of animals and humans. Bimetallic oxides are highly promising for removing various contaminants from water, but doing so on a large scale remains very challenging. Currently, the tiny size of these metal oxides makes it difficult to use them in typical water filtration systems. Scientists are working on attaching bimetallic oxides to a matrix, kind of like a scaffold, which might allow them to be used in water purification [6]. Much more work is needed to continue to develop new, efficient materials that can combat water pollution and protect the health of the environment and humanity.

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YOUNG REVIEWERS



AKSHARA, AGE: 13

I am Akshara, a 13-year-old who had the pleasure of reviewing this article with GM. Anybody who is into anime can easily relate to this article and it makes it memorable. I am grateful for the opportunity.



ALI, AGE: 13

I am Ali, I am 13 years old, and I like playing video games and having fun with my friends and family. I am in a Gifted and Talented track in the middle school. I am deeply interested in Science and Engineering, and I plan to pursue a doctorate in Chemical Engineering as my career inspiration and then teach kids through much simpler ways may be through new innovations and tools. I also think that the current system of educating digital age kids is not efficient and parents and teachers are using age old methods for the new generation.



BILAL, AGE: 15

My name is Bilal, I am a 15 years old high school sophomore. I am on a Gifted and Talented Track. I am deeply interested in medicine and engineering, and I love research, I am fascinated by how stem cells can repair certain cells, tissues and disease. I am currently working on stem cell model systems. As my lifelong goal I plan to pursue medicine but with deep insights and expertise in engineering skills and tools.

AUTHORS



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