May 28, 2021

Earth & Space

Ice production on the hottest planet in our solar system

by **Brant M. Jones** [1] | Professor; **Menelaos Sarantos** [2] | Professor; **Thomas M. Orlando** [1] | Professor

doi.org/10.25250/thescbr.brk541

[1]: Georgia Institute of Technology, Atlanta, Georgia, USA
[2]: Heliophysics Science Division, NASA Goddard Space Flight Center, Greenbelt, USA

This Break was edited by Ayala Sela, Associate Editor - TheScienceBreaker

Observations of Mercury indicate the probable existence of water ice in the permanently shadowed polar regions. Water on the planets of our solar system is thought to be delivered via comets and meteorites. However, water can also be produced from reactions on the soil of Mercury and can distribute in significant amounts to the permanently shadowed regions of Mercury over geological time periods.

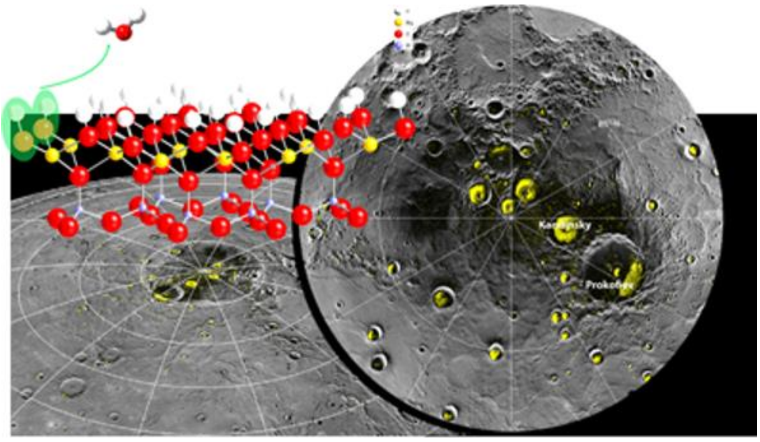

Image credits: Mercury courtesy of NASA, Idealized mineral structure courtesy of Brant Jones, Image compilation courtesy of Ben Brumfield

Water is crucial to life on Earth. It is also present on other planets and solar system bodies. Indeed, ground-based radar observations and space probe data indicated the presence of frozen water ice even on Mercury, the hottest planet in our solar system! Water, in the form of ice, is trapped in the frozen spots of Mercury, where the Sun never shines.

Generally, it is accepted that water is delivered through comets and meteorites. However, there may be an additional source for water, based on solar wind interactions with Mercury's surface. The soil of Mercury is made up of a type of sand similar to olivine here on Earth. These minerals contain different oxides - reactive chemical groups that contain oxygen. As Mercury revolves around the Sun, it is constantly being hit by solar wind - gusts of protons emanating from the Sun. The weak magnetic field on Mercury cannot fully protect it, and these protons strike the surface. Over time, protons will react with the oxide groups in the minerals that make up the soil, and create small ions made up of one oxygen and one hydrogen. When two such ions interact, it can produce water. This reaction requires energy, delivered as high surrounding temperatures of around 200°C. This may seem like a high bar, but the surface temperature of Mercury under the Sun's glare can easily reach 450°C.

On Earth, water cycles between oceans, freshwater reservoirs, ice water and the atmosphere, through rain and evaporation. Can Mercury have its own water cycle without rain and oceans? To answer this question, we created a model to study the evolution of water on the surface of Mercury, while taking into account the components necessary for water production on Mercury (e.g. oxide rich soil, frequent proton access to the surface, and high surface temperatures). Indeed, the model shows that Mercury does have a sort of water cycle. On Mercury, once a water molecule is formed, it is rapidly ejected from the surface into its thin "airless" region known as the exosphere. In the exosphere, the water molecules can be subjected to a wide variety of possible fates including: destruction by the Sun, escape from the planet's gravity, dissociation due to chemical interaction with a hot grain of sand upon landing, and finally - they may condense and accumulate in the permanently shadowed regions. Since these regions are really cold (lower than -150°C), the water molecules form ice.

The model showed that the production of water happens in areas of high proton precipitation and high temperatures. These areas yield the most water near dawn, as the temperature rapidly increases to a value high enough to turn on the chemistry. As the Sun sets, the water chemistry slows down and more protons and oxygen-hydrogen ions move to the surface by diffusion. This allows for the reaction producing water to start again the next morning. On average, the model predicts that approximately 90 metric tons of water (or 3×10^{30} molecules of water)) are created per Mercury day (176 Earth days). However, despite the high production rate, only a handful of water molecules survive the various destructive paths and end up in the permanently shadowed regions.

The permanently shadowed regions must play another important role in order for ice to accumulate - their cold surfaces have to efficiently trap water molecules over geological time frames (that is, billions of years). Indeed, water continually freezes and accumulates at these cold spots, resulting in a detectable water signature. If these permanently shadowed regions were not available, the exosphere would likely have had a higher water content, as water continuously sticks to the surface and desorbs during the night/day cycle, without ice build-up.

In summary, water can form by thermal chemical reactions of solar wind produced products in the soil of Mercury and, over billions of years, gather in significant amounts in the cold, permanently shadowed regions. This leads to a simple water cycle - formation, transport, trapping and ice buildup - a planetary-scale ice maker! The formation of water in this fashion on airless astronomical bodies is likely widespread. Solar wind ions are implanted into the soil resulting in hydrogen-oxygen ions that can then react with one another to form water at a rate dictated by the local surface temperature and concentration of oxide groups in the soil minerals. This simple chemical reaction may also be a significant but unrecognized source for water on other astronomical bodies in our solar system.