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Galileo On Ice

Researchers commemorate the scientist's debate on why ice floats on water

By **Sarah Everts**

Department: **Science & Technology**
Keywords: **Galileo**, **heresy**, **water**, **conference**

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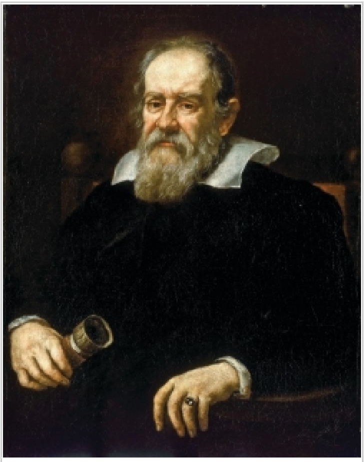

HEADSTRONG
A portrait of Galileo done in 1636 by Justus Susterman.
Credit: Wikimedia Commons/Justus Susterman

Just over 400 years ago, dozens of wealthy spectators gathered in Florence for a highly anticipated debate between the famous astronomer Galileo Galilei and his adversary Ludovico delle Colombe, a philosopher who had long objected to Galileo's experimental data showing that Earth revolved around the sun.

But the debate held during the summer of 1611 was not about our solar system. Instead, the two thinkers were asked to argue a more tangible question: Why does ice float on water, when ice is itself water?

To commemorate the 400th anniversary of this debate, two dozen researchers met in Florence, Italy, for a week in July to discuss current unanswered questions in water research at a conference playfully dubbed Aqua Incognita (which can be translated as Water in Disguise or Unknowable Water).

"Four hundred years after the debate, there are still many unresolved questions about water," said **Barry Ninham**, an emeritus physicist at Australian National University, in Canberra, who organized the conference with University of Florence chemist **Pierandrea Lo Nostro**. For example, modern-day scientists disagree about exactly how water molecules assemble around ions in solution, about whether supercritical water—without distinct gas and fluid phases—is homogeneous and whether it contains hydrogen bonds, and about the physical nature of the hydrophobic effect, when water separates from oil.

The two water deliberations, some 400 years apart, had similarities: Both were multiday events featuring occasional raucous disagreement about experimental details or theoretical constructs. However, with the hindsight of four centuries, the earlier water debate provides a cautionary tale to water researchers—and in fact all scientists—about the double-edged sword of scientific arrogance.

Although Galileo's explanation for why ice floats on water was closer to the truth than his opponent's arguments, Galileo also belittled legitimate, contradictory evidence given by his opponent, said **Louis Caruana**, a philosopher and historian at the University of London and at the Pontifical Gregorian University, in Rome, who described the ancient debate at the recent conference. These face-saving counterarguments were extravagant at best, he added.

Galileo had a lot of self-confidence, Caruana said, which helped him stand up to the church on heliocentricity, using a strong foundation of experimental data. But the scientist's ego also led him to propose—and vehemently defend—some curiously wrong arguments too. For example, Galileo argued that comets were optical illusions (they are most definitely physical objects) and that ocean tides were the result of oceans sloshing around from Earth's rotation (tides have more to do with the moon's gravitational pull). His erroneous arguments during the water debate are a useful reminder that the path to scientific enlightenment is not often direct and that even our intellectual heroes can sometimes be wrong.

Scientific debates were common in 17th-century Italy. They were a chance for the wealthy patrons of scientists—Galileo was backed in this debate by Tuscany's grand duke, Cosimo II de' Medici—to flaunt their support of science. These debates were also a common form of science communication in that era. The mostly lay audiences cheered for quick, publicly accessible answers instead of careful and technical explanations, Caruana noted.

Galileo and delle Colombe spent three days debating the water and ice issue. Delle Colombe's basic premise was that ice was the solid form of water, therefore it was more

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dense than water. He argued that buoyancy was “a matter of shape only,” Caruana explained. “It had nothing to do with density.”

As we know today, delle Colombe’s main argument was wrong: The reason ice floats on water has everything to do with density. Ice is a rare example of a solid that is less dense than its corresponding liquid. Other examples of matter possessing this curious oddity are arsenic, bismuth, gallium, and silicon, Ninham said.

And Galileo’s primary argument for floating ice was correctly based on Archimedes’ density theory, wherein an object in water experiences a buoyant force equal to the weight of water it displaces. Because ice is less dense than liquid water, it will always float on liquid water.

But Galileo then went too far. Aiming at the main thrust of delle Colombe’s argument, Galileo said that the shape of an object did not affect whether the object would sink or float.

TUSCAN JAIL
Galileo was placed on house arrest by the Catholic Church at this villa outside Florence. Other contemporary heretics, such as Giordano Bruno, who held unorthodox religious views and proposed that the sun was a star, were burned at the stake. Galileo escaped this fate by being friends with the pope.

Credit: Sarah Everts/C&EN

Galileo had not accounted for surface tension, however. Surface tension forces can help objects located on a liquid surface resist sinking on the basis of how much of that object is in contact with the liquid’s surface. Consider a paper clip: If it is placed flat on the surface of water it can float, but if it is placed on water standing straight up, it sinks. The difference is the higher surface tension force experienced by the paper clip lying flat on the water’s surface. So in a way, the shape of an object (in contact with the surface) does contribute to whether it sinks or floats.

On the third day of the debate, delle Colombe stole the show with a crowd-pleasing experiment, Caruana said. Delle Colombe presented a sphere of ebony to the audience. The sphere was placed on the surface of the water, and it began to sink. Then delle Colombe took a thin wafer of ebony and placed it on the surface of the water, where it floated. Because the density of both the wafer and the sphere of ebony were the same, delle Colombe announced that density had nothing to do with buoyancy and that an object’s shape was all that mattered.

That’s when “the dispute became noisy and inconclusive, and the meeting was brought to a close,” Caruana said.

The patrons of both delle Colombe and Galileo encouraged the two men to write up descriptions of the debate and their arguments, two records used by scholars such as Caruana to recapitulate the event. Certainly, both debaters realized much was at stake with these write-ups. “Science was dependent on patronage to an extent that is hard for us to accept today,” Caruana said. “A scientist was never fully in control [of research endeavors],” he said.

It’s in Galileo’s report that one finds a “somewhat far-fetched and ad hoc” attempt to explain away the ebony experiment, Caruana said. Galileo argued that when the ebony wafer was floating in water, it was not floating exactly on the surface. It had instead made a little impression in the water and was floating slightly below the surface level of the rest of the water.

Galileo argued that the thin volume of air, above the wafer but below the surface of the water, had somehow united with the ebony wafer. Thus, the density of the hybrid ebony-and-air object was the average of the density of ebony and the density of air. This average density was less than the density of liquid water, thus the ebony wafer (plus air) could float on water.

Caruana described Galileo’s oddball explanation as an “auxiliary hypothesis,” an example of the kind of arguments proposed by scientists who are groping in the dark but still mostly groping in the right direction. “Science rarely involves clear-cut crucial experiments that decide an issue in one go,” Caruana said. He argued that auxiliary hypotheses are a natural part of scientific discourse.

As are heated debates. Given that some of the best debates happen at a bar after an interesting conference session, one Aqua Incognita attendee suggested that the entire group might be able to agree on one point, often attributed to the writer Mark Twain: “Whiskey is for drinking; water is for fighting over.”

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Comments

Markus robert (August 26, 2013 5:36 PM)
Galileo's explanation, "when the ebony wafer was floating in water, it was not floating exactly on the surface. It had instead made a little impression in the water and was floating slightly below the surface level of the rest of the water" sounds very much like an attempt to describe the effects of surface tension.
» **Reply**

Sun CQ (November 18, 2014 7:17 AM)
Recently published resolutions to the following:

1) Why does ice float?
Density and phonon-stiffness anomalies of water and ice in the full temperature range. J Phys Chem Lett, 2013. 4: 3238-3244.

2) Why Ice is so slippery and water so tough?
A common supersolid skin covering both water and ice. Physical Chemistry Chemical Physics, 2014. 16(42): 22987-22994.

3) Why does hot water freezes faster?
Hydrogen-bond memory and water-skin supersolidity resolving the Mpemba paradox. Physical Chemistry Chemical Physics, 2014. 16(42): 22995-23002.

4) How does salt modulate surface tension of water?
Mediating relaxation and polarization of hydrogen-bonds in water by NaCl salting and heating. Physical Chemistry Chemical Physics, 2014. 16(45): 24666-24671.

5) What is the structure of water?
Size, separation, structure order, and mass density of molecules packing in water and ice. Scientific Reports, 2013. 3: 3005.

6) How does water molecules perform in small cluster?
Density, Elasticity, and Stability Anomalies of Water Molecules with Fewer than Four Neighbors. J Phys Chem Lett, 2013. 4: 2565-2570.

7) Why ice is hard to be compressed?
Hidden force opposing ice compression. Chem Sci, 2012. 3: 1455-1460.

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9) overall, more than 10 best known puzzles solved.
Hydrogen-bond relaxation dynamics: Resolving mysteries of water ice,
http://www.sciencedirect.com/science/article/pii/S00108545140027
» **Reply**

PJS (August 26, 2013 6:01 PM)
i think in general when you're talking about "floating" youre not talking about floating due to surface tension, which is a completely different sort of action. your paperclip example is invalid because a paperclip made of styofoam would surely "float" regardless of its orientation...
» **Reply**

Chris (August 27, 2013 5:16 AM)
I don't see how that invalidates that in some instances the shape of an object affects it's ability to float.
» **Reply**

ARaybold (August 26, 2013 6:48 PM)
I don't think Galileo's explanation is as bizarre as it is presented here, though it is still wrong.

If the ebony wafer did depress the surface to the point where its upper surface was below the level of the surrounding water, then it would experience a net hydrostatic force (bouyancy) greater than that experienced by the wafer when fully submerged, or equivalently by the wafer submerged to the point where its top is level with the water and no meniscus is formed.

I think this is the argument Galileo was trying to express: if the wafer has area A, thickness T and mass M, and sits with its lower surface a distance D > T below the surface, it experiences the same net hydrostatic force as a fully-submerged object with area A, thickness D and mass equal to M plus the mass of the air in the volume between the top of the wafer and the level of the water surface. We do have to include the air because it exerts its own additional, though miniscule, pressure on the top of the wafer.

Even if the ebony wafer did lie with its upper surface below the level of the water surface (razor blades seem to, I don't know about ebony), this is still wrong because it does not take into account the surface tension of the meniscus around the edges of the wafer. The additional upward force this exerts prevents the wafer from depressing the surface to the point where the density of Galileo's hypothetical object is no more than that of water.
» **Reply**

Vince Craig (August 26, 2013 7:05 PM)
PJS, I think you've missed the point. You seem to be employing an unusual definition of floating that is only relevant to buoyancy. The definition of floating is to rest or move on or near the surface of a liquid without sinking. This can be due to buoyancy as argued by Galileo, but it also can be due to surface tension as demonstrated by Colombe and illustrated with the paper clip example in this article (water striders are another example). Thus Galileo did not win the argument outright as might be supposed and whilst he observed that a dense article that is floating due to surface tension deforms the interface his explanation for this was that the air and the article combine to form a less dense material which is not in any way accurate. I think we can forgive him, even Newton said surface studies were too difficult.
» **Reply**

sjc (August 26, 2013 7:33 PM)
@PJS

I would like to see your design for a a Styrofoam paperclip which would both be recognizable as such and work. :) I think it is obvious that we are talking about an internationally standard bent ferrous metal paper clip, at standard temperature and pressure.... at the surface of the planet earth, without regard to moon phase, experiencing no stronger magnetic field than that produced by the earth.

But unless this is about bar bets, "papertclip" works. I am just thankful it isn't one of those frictionless, spherical point mass paperclips.
» **Reply**

Mike D. (August 27, 2013 3:10 AM)
A paperclip made of styrofoam would not be a very good paperclip. I think a more accurate name for it would be styrofoam shaped like a paperclip. Regardless of all that, even a bit of styrofoam shaped like a paperclip would float 'better' if it is placed flat rather than pointing straight up.
» **Reply**

Mark B (September 4, 2013 9:17 PM)

"What floats, what fails to float...sinks.
A. Einstein
» **Reply**

Sun CQ (November 18, 2014 7:19 AM)
Resolution to the following:

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