# Study may explain counterintuitive effect of why hotter systems can cool more quickly

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Ever since the days of Aristotle, people have made the counterintuitive observation that hot water sometimes freezes faster than cold water. In modern times, the observation has been named the Mpemba effect after Erasto Mpemba, an elementary school student living in what is now Tanzania in the early '60s. When making ice cream, Mpemba observed that using warmer milk causes the ice cream to freeze faster than when using colder milk.

In the last few decades, the Mpemba effect has been studied and observed in several physical systems besides water, including carbon nanotube resonators and ice-like water cages called clathrate hydrates. Despite these findings, the causes of the effect are not well-understood. Proposed explanations include the presence of impurities, hydrogen bonding, and supercooling. Even the mere existence of the Mpemba effect remains controversial, as one recent study found insufficient evidence to replicate a meaningful effect.

Now, their interest rekindled by a recent paper proposing a generic mechanism for similar effects, scientists Antonio Lasanta and coauthors from universities in Spain have returned to the question in a new study published in *Physical Review Letters*. In their work, the researchers theoretically demonstrate and investigate the Mpemba effect in granular fluids, such as those made of sand or other small particles.

Using simulations of granular systems and a simple kinetic theory approach, the researchers were able to determine that the initial conditions in which the system is prepared play a critical role in determining whether or not the system exhibits the Mpemba effect. Their analysis also enabled them to identify the initial conditions required in order for a granular system to exhibit the Mpemba effect.

"Our work shows that the existence of the Mpemba effect is very sensitive to the initial preparation of the fluid or, in other words, to its previous history," coauthor Andrés Santos at the University of Extremadura in Badajoz, Spain, told *Phys.org*. "In our opinion, this may explain the elusiveness and controversy of the Mpemba effect in water, as a consequence of the lack of control on the detailed initial preparation of the sample."

As the researchers showed, if a system is not prepared under certain initial conditions, then the colder system cools down more quickly than the warmer one, as expected, and there is no Mpemba effect.

"We theoretically showed, at least in the case of a gas, that a system's temperature evolution and thus its cooling and/or heating rate do not depend on initial temperature alone, but also on the previous history of the system that control the initial value of the additional variables," Santos said. "Therefore, it is perfectly possible that an initially heated system cools down quicker than a colder one with a different history."

As the researchers explained further, the simplicity of the Mpemba effect in granular fluids compared to water and other systems enabled them to reach this conclusion.

"Our results show that the Mpemba effect is a generic non-equilibrium phenomenon that appears if the evolution of temperature depends on other physical quantities that characterize the initial state of the system," Santos said. "In practice, such an initial state can be experimentally achieved if the system is taken by some physical procedure very far away from equilibrium (for instance, by a sudden heating impulse prior to cooling down). Our theoretical and computational work shows that the Mpemba effect is particularly simple in a granular gas, since, in practice, there is one single extra parameter controlling the Mpemba effect. This parameter is the kurtosis, which measures the deviation of the velocity distribution function from a Gaussian distribution."

With this new understanding, the researchers could estimate a range of initial temperatures for which the effect emerges and determine how different the initial values of this parameter must be in order for the Mpemba effect to appear.

The results also support predictions of the existence of an inverse Mpemba effect: when heated, a colder sample may reach a hot target temperature sooner than a warmer sample. The researchers plan to investigate this area and others in the future.

"On the theoretical side, we plan to carry out a similar study in the case of a molecular solute (where collisions are fully elastic) suspended in a solvent that produces a nonlinear drag force on the solute particles," Santos said. "Going back to granular fluids, we also want to analyze the impact of particle roughness and spin on the Mpemba effect. In the latter system, the simplest model would couple the temperature evolution to that of the parameter measuring the non-equipartition of energy between the translational and rotational degrees of freedom.

"On the experimental side, we think that reproducing in a laboratory the Mpemba effect in a granular gas would be a breakthrough. We are currently working on the design of an ad hoc experiment."

**More information:** Antonio Lasanta et al. "When the Hotter Cools More Quickly: Mpemba Effect in Granular Fluids." *Physical Review Letters*. DOI: 10.1103/PhysRevLett.119.148001. Also at arXiv:1611.04948 [cond-mat.soft]