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STUDY OF THEMPEMBA EFFECT

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ABSTRACT

The paradox of Mpemba effect implies that water with higher initial temperature can be cooled down to 0°C more quickly [1]. Although the effect might appear impossible, it has been observed in numerous experiments and was discussed by Aristotle, Francis Bacon, Roger Bacon, and Descartes [2].

In this report study of the various researches and the factors responsible for the effect has been done. There is no one mechanism that explains the Mpemba effect for all the circumstances but instead there are many different mechanisms important under different conditions. More recent studies have suggested that the effect of dissolved gases particularly carbon dioxide and supercooling may be more significant [3]. Also factors such as evaporation, convection currents and environmental conditions also play a very important role in occurrence of Mpemba effect.

***Keywords*: Mpemba Effect, Convection, Supercooling, Evaporation, Dissolved gases.**

I. INTRODUCTION

Nothing could seem more mundane and well understood than water. This apparently simple two hydrogen-one oxygen compound is a fundamental component of all living organisms. Yet this extremely common compound has some strange, puzzling and counterintuitive properties. This paper is based on one such peculiar property of water known as Mpemba effect which states that hot water freezes faster than the cold water when they are present in equal volumes.

This phenomenon was first noticed by Aristotle who said, “If water has been previously heated, this contributes to the rapidity with which it freezes: for it cools more quickly. Thus so many people when they want to cool water quickly first stand it in the sun”.

Mpemba effect was reintroduced by Erasto Mpemba in 1963. In 1963, a Tanzanian high school student (Erasto B. Mpemba) noticed that his hot ice cream mix froze faster than the cold mixes. With great persistence despite the disbelief of his teachers, he insisted on his experimental observations over theory.

There is no one mechanism that explains the Mpemba effect for all circumstances but instead there are many different mechanisms important under different conditions.

Progress in the experimental elucidation of this phenomenon has been hampered largely by the vast number of variables that need to be examined.

II. HISTORY

Almost 50 years ago a Tanzanian schoolboy Erasto Mpemba obtained an unusual result, trying to make ice-cream. He observed that the liquid with higher initial temperature froze earlier. Mpemba effect has been known for centuries; however it became a scientific quest only after Erasto Mpemba observed this in 1963 and started asking the scientific community for explanation. With great persistence despite the disbelief of his teachers, he insisted on his experimental observations over theory. Since then, a number of experiments have confirmed and reproduced from the initial observation. In 13th century Roger Bacon agrees that hot water can under some circumstances freeze faster than cold water, but argues that specification of the precise experimental conditions is important. Belief in the Mpemba effect continued strong into the 17th century, Francis Bacon and Descartes both wrote extensive works on the scientific method and experiments, and both wrote about the Mpemba effect. In 1637 Descartes wrote about this phenomenon in Les Meteores, a work that was published as an attachment to his more famous Discourse on Method**.** A modern writer on Descartes did not measure the time for the hot water to freeze, but wrote that when water has been heated, it is somehow changed so that it cools more easily, even after being brought back to room temperature. With the advent of the modern theory of heat transfer, these earlier observations were forgotten. Research focus not on the point at which water of different temperatures freezes, but rather, the rates of cooling for "warm" and "cold" water. Multiple explanations have been proposed for the effect. The Mpemba effect is a paradox if the state of cooling water in a beaker is assumed to be characterized by the average temperature only.

N. Ernest Dorsey in 1948 stated that heating a specimen of water may or may not cause it to freeze before a cold specimen. There is no one mechanism that explains the Mpemba effect for all circumstances, but instead, there are different mechanisms important under different conditions. Mpemba effect is explained by considering the difference in particle energy distributions of hot and cold water samples. The Mpemba effect provides a lovely case for considering these issues, because although it provokes scepticism, it has been observed in multiple experiments yet, in support of the sceptical position, it is observed that the experimental results are not consistent and that the theoretical situation is still unsettled.

III. PROBLEM STATEMENT

"There exists a set of initial parameters and a pair of initial temperatures such that given two bodies of water identical in these parameters, and differing only in their initial uniform temperatures, the hot one will freeze sooner."

Once the Mpemba effect is properly stated, it is clear that we are only looking for some set of parameters, such that if we plot the freezing time versus the initial temperature, there is some range of initial temperatures for which the effect holds. Restriction of the effect to a specific class of parameters is logically necessary for the problem to be at all reasonable, but this point is not always appreciated in popular discussions.

Further consideration of this point brings up another issue. Logically, our statement about the Mpemba effect can never be proven false. Regardless of the number of experiments that fail to see the effect, a believer in the Mpemba effect can always claim that the effect occurs for other sets of initial parameters that differ slightly from the ones used.

Several parameters can plausibly be considered important. Furthermore, their effects are not independent of one another. But an experimenter cannot be expected to establish a vast multidimensional array of containers with different dimensions and shapes, independently varying masses, gas contents, and refrigeration methods. We do not claim that a scientific investigation of the Mpemba effect is impossible. But a common response upon first hearing about the Mpemba effect is that it should be straightforward to study experimentally. To the contrary, even for this deceptively simple problem, productive experimental design requires at least some theoretical understanding of why the effect might occur—otherwise we will not know whether we should consider, for example, the gas content of the water. We will see that because the time to freezing is sensitive to many parameters, the experimental results become very confusing.

Our statement of the Mpemba effect now reads "There exists a set of initial parameters mass and gas content of the water, container shape and type, and refrigeration method, such that given two bodies of water identical in these parameters, and differing only in their temperatures, the hot body will freeze sooner." One final difficulty that must be considered is how to define the time of freezing—do we consider it to be frozen when ice crystals first appear or only when the entire body of water is frozen? Or, to simplify the experiment, we might just measure the time until some specified part of the water reaches 0 °C. This issue might seem minor, but it is potentially crucial.

IV. SCOPE

Even if the Mpemba effect is real - if hot water can sometimes freeze more quickly than cold-it is not clear whether the explanation would be trivial or illuminating. The required vast multidimensional array of experiments might explain why the effect is not yet understood.

How is this possible? The remarkable thing is that nobody really knows, even though the first observations were reported to the scientific community in 1969. The story of the discovery, and the consequent mystery, is worth a bit of exploration — and the Mpemba effect carries numerous important lessons about the nature and method of scientific discovery.

The Mpemba Effect remains a very real phenomenon with impacts outside of the lab. Besides Member's ice cream observation, this effect can be seen in other aspects of daily life. The recent fad of making "instant snow" on chilly days by throwing boiling water up into the air is a manifestation of the Mpemba Effect. Room temperature water thrown up into cold air results in nothing more than the water falling to the ground. Despite such interesting observations, the Mpemba Effect remains an unsolved mystery.

The importance of the Mpemba effect is debatable. Since it is so difficult to determine the causes of the effect, any applications of the effect are far off in the future. Until an effective experiment can be performed we will never know if the causes of the Mpemba effect are in fact trivial or are instead of a great importance and will help us further understand our universe.

V. THE EXPLANATION

Various reasons have been proposed by different researchers and scientists to explain the occurrence of Mpemba effect. However there is no one acceptable explanation that summarizes why Mpemba Effect exactly occurs.

It is not likely that in all reported cases of hot water freezing prior to a cold one the difference in the temperature of the iceboxes was the cause, it is possible that the matter derived confusions and misinterpretations of the results in some cases.

Melting of the frost enabling better thermal conduction, are also often mentioned but this aspect will not be given further attention in this paper, since enough data is provided to show that Mpemba effect occurs even when melting of the frost in icebox is hampered or completely excluded.

Theories on why hot water freezes more quickly than the colder one, and the Phenomena most often accused of causing it are:

1. Evaporation of the water.
2. Dissolved gasses.
3. Heat gradient induced convection.
4. Effect of particle energy distribution on the dissipation of radiation energy
5. Super cooling.

A careful consideration of the Mpemba effect allows us to define one single necessary condition for the effect to occur: As the initially warmer water (at temperature θ_h) reaches the temperature of the initially colder water (θ_c) it's properties must be changed in the way that the rate of further cooling (from θ_c to freezing) is increased or the temperature of freezing (super cooling) is significantly lowered. This differentiation may occur during the process of heating the sample to θ_h or cooling it from θ_h to θ_c. If this is not achieved, Newton's law of cooling and not to mention common sense, tell us Mpemba effect is not possible.

1. Evaporation of the water:

Initially hot water as it cools loses more heat and mass by evaporation than initially cold water. With less mass, the initially hot water has a smaller enthalpy of freezing, hence takes shorter time to freeze.

Vaporization phenomenon is not a relevant cause of the Mpemba effect.

By sealing a sample, not only the vaporization, but also thermal conduction would be hindered making impossible to examine each effect separately.

2. Dissolved gasses:

Gas molecules stiffen the arrangement of the water around them reducing convection in the sample. This means that the viscosity of the water should be significantly increased as gasses dissolution is favoured.

Ostwald showed this was not true in the case of any air contained gas. Namely, saturating water with carbon dioxide, oxygen or nitrogen, did not change the viscosity of the sample in reference to pure water.

Warmer water contains less gas it is logical to assume that during cooling more and more gas is being dissolved in it. This process is exothermic which means that it "produces" heat, which should slow down the process of cooling, not speed it up [3].

3. Heat gradient induced convection:

The hotter water initially is, the more convective flow is induced in it, which makes the cooling to the freezing point faster.

The convective flows depend on the viscosity of the media. As viscosity of the water increases exponentially with decrease in temperature the convective flow is much easier to induce at higher temperatures.If all other physical conditions are equal, except temperature, a better thermal contact with a colder surface is the only reason that hot water will cool to zero degree before cooler water.As the heat gradient increases, the convection is more defined, and the overall cooling of the water sample isfaster, this is because the heat gradient on the walls of the container is maintained[4]. It should be noted that convection has both properties required to cause Mpemba effect; the flowinduced during the cooling from θ_h to θ_c continues throughout the cooling. This enhances the heat transfer from the water sample. In other words, the hotter water initially is,the more convective flow is induced in it, which makes the cooling to the freezing pointfaster[5].

4. Effect of particle energy distribution on the dissipation of radiation energy

When a water sample is heated from room temperature, particle energy distribution within the sample will change rapidly. The addition of new higher-energy levels during the heating process will make the energy distribution curve to grow on high-energy side resulting in a wider energy distribution curve. This energy distribution will not return to its original status when the sample is cooled down to the room temperature. This is because a sample in room temperature will have the least variation in particle energy (narrow energy distribution curve) because such a sample is normally taken from a source that has been kept in near constant temperature for a long period of time. During this long period, the interaction between particles with different energy levels would have resulted in sharing the energy, thereby stabilizing the energy levels. However, the cooling time for a hot water sample is only few hours; this period is not long enough to change the wide energy distribution curve of hot water to the original status of stabilized narrow curve. Hence a hot water sample will have a larger variation of energy levels (wider energy distribution curve) during the whole cooling period, compared to unheated samples.

It has been shown by calculations done by Piya R. Piyasena [6] in his paper that a sample with larger variation of energy levels (wider distribution curve) will dissipate more radiation than a sample with smaller variation of energy levels (narrow distribution curve), calculated at the same temperature. Consequently a hot water sample will dissipate more energy, and will have a higher cooling rate than a cold water sample throughout the cooling period leading to the Mpemba Effect.

When a water sample is heated its average kinetic energy (temperature) and the number of particles with higher energy levels increases.

When the sample is cooled, the average kinetic energy decreases, but a large proportion of high-energy particles will still remain in the sample.

Unheated samples will have only a very small number of high-energy particles, as most of the particles will have energy levels close to average energy. The presence of large number of high-energy particles in a heated water sample will result in higher radiation energy dissipation. Therefore, a hot water sample will have a higher cooling rate than a cold water sample, leading to the Mpemba Effect.

VI. SUPERCOOLING AND MPEMBA EFFECT

Consideration of supercooling greatly complicates the Mpemba effect, and it is not clear how or whether it helps to explain it.

Auerbach considered the relevance of supercooling to the Mpemba effect. He found that initially hot water would supercool less than initially cold water. Auerbach did not determine the reason, but pointed out that the initially hotter water should have greater temperature gradients, and that the presence of a gradient is known to trigger crystallization. However, his observation that heated water supercools less than non-heated water is opposite to the findings of Brown and Dorsey. Auerbach did a relatively small number of trials so the significance of his results is unclear.

Although Auerbach's result is in the correct direction to explain the Mpemba effect he found that the initially hot water took longer to freeze on average.

He found that when the ambient temperature $T_a$was −5°C>T_a> −8°C, the probability of a randomly chosen container of initially hotter water freezing before a randomly chosen container of initially colder water was 53%. For −8 °C>T_a> −11°C, the probability was 24% [2].

VII.CONCLUSION

Understanding the Mpemba effect stills seems like a distant goal and while many researches have been already done on this topic, this still doesn't give a satisfactory explanation of why Mpemba effect actually occurs. It has been suggested that mass loss associated with evaporation could result in faster freezing of water.

It has been suggested by some researchers that since hot water contains less amount of dissolved gases than cooler water, this might be one of the important factor that may be responsible for this phenomenon but still there's not enough theoretical or experimental evidence to back this point.

The concentration of dissolved gases in water such as nitrogen, oxygen and carbon dioxide decrease as the temperature of water increases. The relative paucity of these gases in hot water may enhance the ability of water and ice to transfer heat. Carbon dioxide alone was found to have significant influence.

The hot water supercools, but only slightly, before spontaneously freezing. **S**upercool several degrees below 0^{o}C before latent heat is released and the temperature of the water rises to 0^{o}C and freezing begins.

The question still remains as to why Mpemba effect actually occurs and what other types of fluids might exhibit this same phenomenon and the range of the temperature over which this effect can be detected.

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