

Making Ice Cream and Scientific Thinking

A True Story about a Thinking Student

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What do you think about this question: If you take two containers, fill them with equal volumes of a liquid, one hot and the other cold, and put them into the freezer at the same time, which will freeze first?

You might think that the editor confused my manuscript with that of a primary school physics book. We indeed are going to see students and things about children in the article, but I do not suggest that you give a confident answer to the question!

In the 1960s, there was a schoolboy named *Erasto B. Mpemba* in Tanzania, Africa. At his school the pupils loved to make ice cream. They bought some milk at the market, boiled it, mixed it with sugar, and put it into the refrigerator of the school. There was not much space in it, so the boys always tried to quickly obtain a place for their ice cream.

One day, as Erasto was boiling his milk, he noticed that another boy was putting his milk into the refrigerator without boiling it. He did not want to miss the space and, hurrying, he did not wait until his milk cooled down to room temperature, but put it into the freezer hot (even at the risk of ruining it).

One and a half hours later they went back, and found that his ice cream was ready, while his friend's was not yet completely frozen.

Erasto found this unusual and asked his physics teacher at the school why this happened. The teacher answered: "You were confused, that cannot happen."

Then he believed this answer, and did not bother to try the experiment again (even when, in his next holiday, he met some ice cream selling friends who told him that they also start freezing the cream while hot, because that way it is ready quicker).

Some years later Erasto Mpemba became a high school student. The first topic they were dealing with in physics was heat. When hearing about Newton's law of cooling, Erasto Mpemba asked the teacher: "Please, sir, why is it that when you put both hot milk and cold milk into a refrigerator at the same time, the hot milk freezes first?" The teacher replied: "I do not think so, Mpemba." But the student stated that he had seen it himself. The teacher said: "The answer I can give is that you were confused." And when he insisted on his opinion, the teacher told him: "All I can say is that that is Mpemba's physics and not the universal physics." (And later on, the whole class would criticise all his mistakes saying "That is Mpemba's mathematics" or whatever it was.)

Mpemba did not want to leave this case at that. One day, as he found the biology laboratory of the school open and empty, he quickly went in, filled two beakers with hot and cold tap water and placed them into the freezer. As he returned one hour later, he found that neither of them had frozen yet, but there was more ice in the originally hot water. However, this was not conclusive, so he decided to continue to deal with the topic.



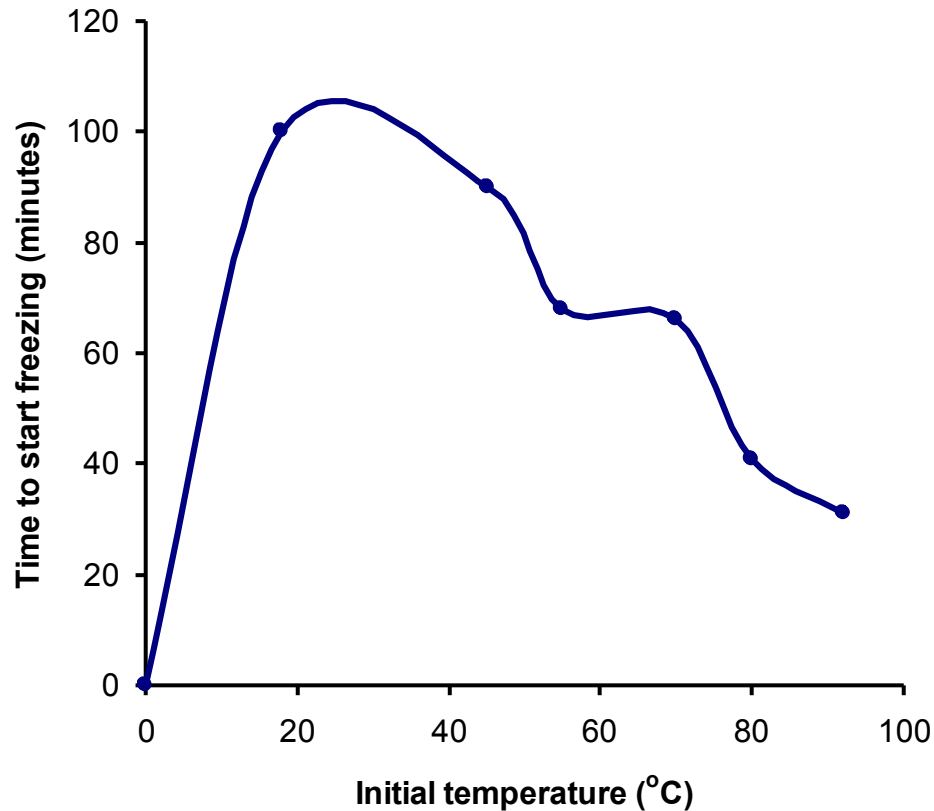
Later, *Dr Denis G. Osborne*, professor at University College Dar es Salaam (then capital of Tanzania) visited their school. He gave a lecture to the students and after that they were allowed to ask questions. Erasto Mpemba took courage and asked: “If you take two similar containers with equal volumes of water, one at 35 °C and the other at 100 °C, and put them into the refrigerator, the one that started at 100 °C freezes first. Why?” The professor did not ridicule the student. He recalls: “I confess that I thought he was mistaken but fortunately remembered the need to encourage students to develop questioning and critical attitudes. No question should be ridiculed. [...] everyday events are seldom as simple as they seem and it is dangerous to pass a superficial judgment on what can and cannot be.” He answered the student: “The facts as they are given surprise me, because they appear to contradict the physics I know. But I will try this experiment when I am back in Dar es Salaam.” And he encouraged the questioner to repeat the experiment himself, too.

Mpemba became an anti-hero at his school. His classmates told him that he had shamed them, and that his aim was to ask a question which the professor would not be able to answer, others asked him: “But Mpemba, did you understand your chapter on Newton’s law of cooling?”¹

But he did continue experimenting at the school. His results were just the same. He showed everyone what happens. When the head teacher of the physics department heard that it worked, he said: “It should not.” (But added: “I will try it this afternoon.” And found the same results.)

Meanwhile, Dr Osborne, back at his workplace, also let a young technician test the facts. He reported that in the first trial the hot water froze first, and added: “But we will keep on repeating the experiment until we get the right result!” They indeed repeated it. The results are plotted in the next figure.

¹ Newton’s law of cooling states that the rate of cooling is proportional to the temperature difference between the object and the cooling environment – *under some simplifying assumptions*.



Results of Dr Osborne's detailed experiments

As visible, the curve has a maximum at about 30 °C.

Articles were published, experiments were repeated everywhere. The latter is not an easy task, because there are many factors influencing what exactly happens (like the geometry and the material constants of the objects – the freezer, the container and the liquid –, the ratio of the top surface area and the volume of the liquid, etc.) Under some conditions the effect does not even occur: the cooler liquid freezes first.

We shall see some theories which attempted to explain this phenomenon. It is important to know that even today there is no proved or accepted explanation!

1. Some thought that the hotter glass had melted the frost layer in Mpemba's refrigerators, and this way it got into a much better contact with the freezer (because frost is a bad thermal conductor). In some experiments it might have happened, but eliminating this effect does not stop the phenomenon.

2. During the cooling evaporation also occurs. Evaporation needs heat and removes mass from the liquid – both let the cooling be faster. Of course in the hotter liquid these effects are stronger. However, from theoretical calculations and experiments eliminating evaporation we know that this explanation is insufficient.

3. Above 4 °C, the density of water increases as temperature decreases. As the top layer (where cooling is the most intensive) has transmitted heat to the environment, it becomes cooler, hence denser. It starts to sink down to the bottom of the beaker, from where warmer water is arriving to the top. These convection currents established by temperature gradient are more intensive in the initially hotter liquid, which makes heat transmission at the top faster. The temperature gradient undoubtedly exists, but these currents have been neither theoretically described nor thoroughly experimentally observed.

4. Some investigators stated that gases dissolved in the liquid can play a role in causing the effect. Of course there is less dissolved gas in the hot water, and dissolved gases might change the thermodynamic constants of the solvent, but there is no exact theory to explain why and how they do.

5. Finally, supercooling can give an answer. It was observed that the initially warmer water can be supercooled less. (But there is only a very complicated and not undoubtedly valid explanation why this happens.)

We can say that the faster freezing of the initially hotter water is most probably the result of *several effects at the same time*.

People also began to look for earlier references in literature. It turned out that this phenomenon could have been a common idea. (Remember the ice cream sellers!) But by official science it was forgotten until 1969. Some historic statements:

René Descartes (1637): “Experience shows that water which has been kept for a long time on the fire freezes sooner than other water.”

Francis Bacon (1620): “Water slightly warm is more easily frozen than quite cold.”

Giovanni Marliani, medieval physicist dealing with heat: in a debate (c1461) stated that he had taken four ounces of boiling water and the same volume of non-heated water, placed them outside in a cold winter day, and had found that the boiling water froze first. He quotes an even earlier source:

Aristotle (c350 BC): “The fact that water has previously been warmed contributes to its freezing quickly; for so it cools sooner. Hence many people, when they want to cool water quickly, begin by putting it in the sun...”

This phenomenon was named *the Mpemba effect* after this brave student. The story is a parable for everybody forever, not to undervalue the observations of uneducated people, and not to state too quickly that something is impossible.

The story warns us that it is worth reflecting on this: Do not we often have serious prejudices in discovering nature? Can we really observe our world clearly and without bias? Like Erasto Mpemba did, and like children do. Can we wonder at the interesting, beautiful things around us? (The younger a child is, the more they do so.)

An interesting statement is recorded from Jesus Christ: “Unless you become like little children, you will never enter the kingdom of heaven.” It seems so, that important things in life can be correctly, really understood with “a child’s mind”. Open-hearted and putting aside prejudices.

I hope we can all learn to observe the world this way!

Dr Osborne and Mpemba never became famous, their names cannot be found in any biography collection. I would welcome any information about their later destiny.

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- (Words of **Jesus Christ**) Bible, New Testament, the gospel of Matthew, chapter 18 verse 3 (quoted from the *New International Version*)