? Hot stuff

Is it true that hot water placed in a freezer freezes faster than cold water? And if so why does this happen?

Ian Popay
Hamilton, New Zealand

This question was raised many years ago in New Scientist *and never answered satisfactorily. This time we are closer to settling the controversy with answers from several people who have tried the right experiments. Counter-intuitive though it may be, it does appear that hot water can freeze more quickly in a refrigerator. Better thermal contact if the water container is placed into an iced-up freezer compartment and a different pattern of convection currents which allow hot water to freeze faster seem the best explanations. Which effect predominates depends on the fridge, the container and where it is placed – Ed.*

The questioner is correct – it is possible to produce ice cubes more quickly by using initially hot water instead of cold. The effect can be achieved when the container holding the water is placed on a surface of frost or ice. The higher temperature slightly melts the icy surface on which the container rests, greatly improving the thermal contact between the container and the cold surface. The increased rate of heat transfer from the container and contents more than offsets the greater amount of heat that has to be removed. The effect cannot be obtained if the container is suspended or rests on a dry surface.

This effect was first noted by Sir Francis Bacon using wooden pails on ice. My own investigation showed ice cubes could be obtained within 15 minutes rather than 20 minutes if the frost in the refrigerator was deep enough. The incentive to get your ice a little quicker is obviously greater in Australia than in cooler countries.

Michael Davies
University of Tasmania, Australia

But Sir Francis Bacon was not the first to note the effect. Aristotle's account in *Meteorology* below implies a similar explanation: 'Many people, when they want to cool water quickly begin by putting it in the sun. So the inhabitants when they encamp on the ice to fish (they cut a hole in the ice and then fish) pour warm water round their rods that it may freeze the quicker; for they use ice like lead to fix the rods.'

David Edge
Hatton, Derbyshire, UK

And it seems untrue that the 'effect cannot be obtained if the container is suspended or rests on a dry surface'...

This question was raised in *New Scientist* in 1969, by a Tanzanian student named Erasto Mpemba. He discovered that ice-cream mixture froze more quickly when put in the freezer hot than if allowed to cool to room temperature first. I got the same sceptical comments from my teachers as Mpemba did when I based my sixth-form project on his question.

First, the project showed that water, either from the tap or distilled, behaved in the same way as ice-cream mixture; the chemical composition is not important. Second, it demonstrated that a reduction in volume by evaporation from hot water was not the cause. Placing thermocouples into the water showed that water at about 10 °C reached freezing point more quickly than water at about 30 °C, as predicted by Newton's law of cooling, but that thereafter, water that started off warm solidified more quickly.

In fact, the maximum time taken for water to solidify in the freezer occurred with an initial temperature of about 5 °C, and the shortest time at about 35 °C. This paradoxical behaviour can be explained by a vertical temperature gradient in the water. The rate of heat loss from the upper surface is proportional to the temperature. If the surface can be kept at a higher temperature than the bulk of the liquid, then the rate of heat loss will be greater than from water with the same average temperature, uniformly distributed. If the water is in a tall metal can rather than in a flat dish, the paradoxical effect disappears. We argued that temperature gradients in the tall can were short-circuited by heat conduction through its metal walls.

The question has certainly made me reluctant to take accepted wisdom for granted when it comes to observations which do not fit preconceived notions of what is correct.

J. Neil Cape
Penicuik, Midlothian, UK

The classic experiment uses two metal buckets placed in the open air on a cold, preferably windy, night. Stationary water is a poor conductor of heat and ice forms on the top and around the sides. If the initial temperature is around 10 °C, cooling of the core is very slow, particularly as loose ice floats to the top, inhibiting normal convection. There is no means by which the warmer water can come into contact with the cold bucket and transfer its energy to the outside.

If the initial temperature is about 40 °C, strong convection is established before any water freezes, and the entire mass cools rapidly and homogeneously. Even though the first ice forms later, complete solidification of the hot water can occur more quickly than if the water starts off cold.

The conditions are critical. Obviously, if the cold bucket starts at 0.1 °C and the hot at 99.9 °C the experiment is unlikely to cause surprise. The containers must be large enough to sustain convection with a small temperature gradient, but small enough to extract heat quickly from the bucket's surfaces. Forced air cooling on a windy night helps.

It is difficult to generate suitable conditions in a domestic freezer but the anomaly can be demonstrated in an industrial chiller or a laboratory environmental chamber.

Alan Calverd
Bishop's Stortford, Hertfordshire, UK

It's true and I have verified the assertion by experiment. The only limitation is that the container of water must be relatively small so that the capacity of the freezer to conduct away the heat content is not a limiting factor.

Cold water forms its first ice as floating skin, which impedes further convective heat transfer to the surface. Hot water forms ice over the sides and bottom of the container, and the surface remains liquid and relatively hot, allowing radiant heat loss to continue at a higher rate. The large temperature difference drives a vigorous convective circulation which continues to pump heat to the surface, even after most of the water has become frozen.

Tom Hering
Kegworth, Leicestershire, UK

This is a cultural myth. Hot water will not freeze faster than cold water in the freezer. However, hot water cooled to room temperature will freeze faster than water that has never been heated. This is because heating causes the water to release dissolved gases (mostly nitrogen and oxygen) which otherwise reduce the rate of ice crystal growth.

Tom Trull
University of Tasmania, Australia

Sceptical Tom Trull from the University of Tasmania might like to stroll over to the refrigerator of the first letter-writer, Michael Davies, also from the University of Tasmania. The experimental evidence suggests that the effect is real – the absence of dissolved gas could be another factor that speeds crystal growth.

And there could be yet another factor that none of our letter-writers have described – supercooling. More recent research shows that because water may freeze at a variety of temperatures, hot water may begin freezing before cold. But whether it will completely freeze first may be a different matter – Ed.

In scientifically controlled experiments this effect seems to be real. We assume that the temperature in the freezer stays constant during the freezing process, as do the variables of the samples such as container size, conduction and convection properties inside and outside the container.

However, I feel that one more variable is present and that is an overlooked temperature variation in the freezer. The temperature oscillation inside the freezer depends on the sensitivity of the thermoelement and the timer of the controller system. We may assume that at the freezer's standard temperature the power used for cooling the freezer operates at a standard rate. If a bucket of cold water is added, it may produce only a small effect on this power output as it will not trigger the temperature sensor. However, a bucket of hot water may easily activate the sensor and release a short but powerful cooling of the freezer with a cooling overshoot, depending on the timer.

This may be overlooked by an observer at home. I have seen a similar effect in an electric sauna. By fooling the temperature sensor by splashing water I increased the oven's output.

Matti Jarvilehto
University of Oulu, Finland

Recent, as yet uncorroborated, research from the University of Washington at St Louis, US, has offered yet another possibility. Solutes, such as calcium and magnesium bicarbonate, precipitate out if water is heated. These can be seen inside any kettle used to boil hard water. However, water that has not been heated still contains these solutes and as it is frozen the ice crystals that are forming expel the solutes into the surrounding water. As their concentration increases in the water that has yet to solidify they lower its freezing point like salt sprinkled on a road in winter. This water therefore has to cool further before it freezes. Additionally, because the lowering of the freezing point reduces the temperature difference between the liquid and its surroundings, the heat loss from the water is far less rapid – Ed.