Measurement At Home

Report on ‘Measuring tap water temperature using sugar’

1. Overview

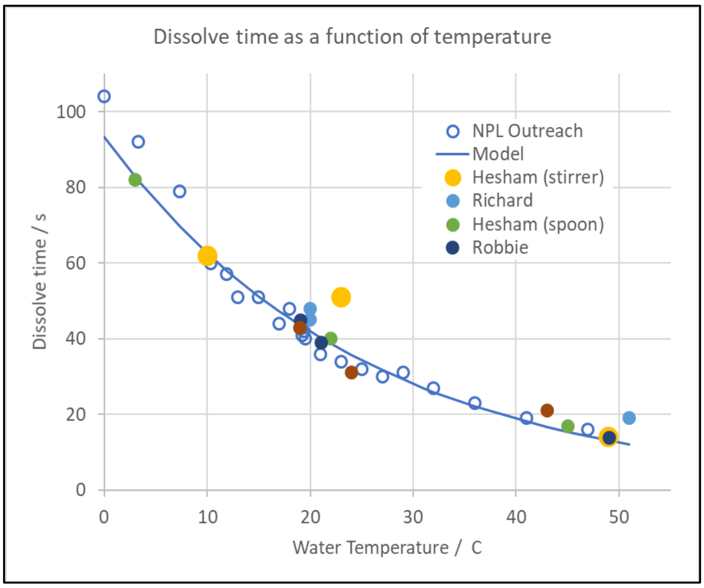
This report uses results received within a few days of issuing the challenge. **Thank you: Andrew, Elizabeth, Gordon, Hesham, Richard and Robbie.**

The overall finding was that **the time sugar takes to dissolve reduces with temperature** – supporting the molecular motion model of temperature. We used people’s results to create a mathematical model which can be used to indicate water temperature from sugar dissolve time (so long as people follow the procedure carefully). Elizabeth also investigated how kitchen salt performed in the same test and found **salt dissolves quicker than sugar, yet similarly - faster as water temperature increased.**

2. Does this method work?

In the chart here (right), each dot represents a result obtained by NPL and other participants.

NPL Outreach’s 25 separate measurements used blends of water from a kettle and freezer to achieve different temperatures, and these, combined with others’ data were used to create a ‘best fit’ curve which is also plotted. This modelling approach is commonly used in science, with the particular mathematical model (causing the curve’s shape) chosen to reflect the scientific understanding of the process. This is a ***rate of reaction*** experiment, so we expect an exponential relationship (a precise mathematical term). NPL made many more measurements than others, so their approach will dominate the curve-fit, though everyone’s data seems to be similarly close to the curve suggesting they all fit the model equally well.



At any given temperature, the range in dissolve time is about ±5 seconds, or if we use the graph to convert time to temperature, a time reading can be trusted to provide a temperature value to about ±4 °C.

There were some ‘outliers’. Below 10 °C NPL results take longer to dissolve than the model predicts (perhaps something special happens to water below 10 °C). ‘Hesham stirrer’ room temperature water takes much longer to dissolve than the model predicts. Hesham admitted he stirred faster than 100 stirs per minute using a narrow wooden stirrer instead of a spoon which could explain a longer dissolve time, though his hot and cold tap results agree well with the model.

Gordon said he couldn't measure the amount of sugar and assumed a teaspoon held about 4 g. Teaspoons vary in size. A level 'metric' teaspoon holds 5 ml whereas Wikipedia describes a US teaspoon as having a capacity of 4.92892159375 ml (a rather silly number of significant figures!), other sources claim different values, and there is the standard Canadian teaspoon... You can see why we measured sugar by mass. We did some checking and found varying sugar amount by 25% in this experiment changed dissolve time by about 5%.

3. How does salt dissolving rate compare with sugar?

Elizabeth did the experiment with both salt and sugar though did not have a thermometer so her results were not used in section 2. Her results are in this table (right).

	Time taken to dissolve /s		
Water	Cold tap	Room temperature	Hot tap
Sugar	53	36	21
Salt	18	12	6

Elizabeth shows that both salt and sugar dissolve faster as water temperature increases, and that salt dissolves faster than sugar. She suggested this was because her salt grains were smaller than her sugar grains, and some factors are summarised in the table below.

Aspect	Kitchen Salt (NaCl)	Granulated Sugar ($C_{12}H_{22}O_{11}$)
Grain size	Usually smaller than granulated sugar	Usually larger than kitchen salt
Chemical base unit	Smaller: 1 ion each of sodium and chlorine	Larger: molecule comprising 45 atoms (12 carbon, 22 hydrogen and 11 oxygen)
Number of base units in a given volume	Many more than sugar	Many less than salt
How it dissolves in water	Individual sodium and chlorine ions split from crystal and mix in water	Molecules disconnect from crystal but remain as full molecules in water

The surface area to volume ratio has a big effect on reaction time. Smaller pieces react faster as they have more reacting surface area for the same volume. Salt is smaller than sugar both for grain size and at the microscopic base unit scale.

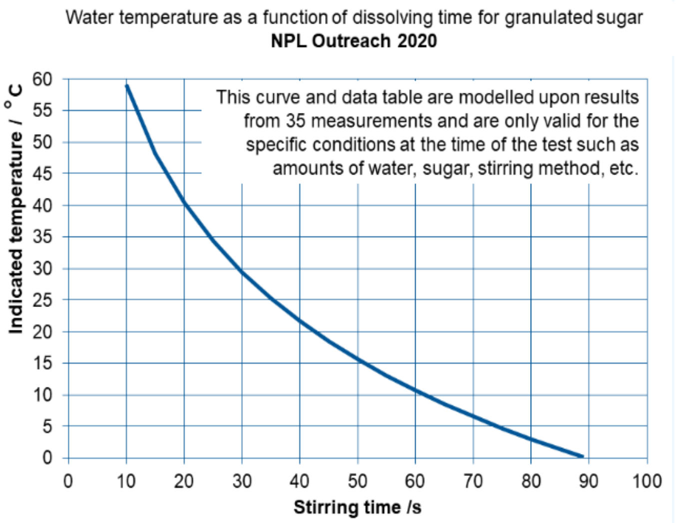
4. How reliable is this method?

The results all show the same trend – that sugar (and salt) dissolves faster in hotter water. We used collected data to create a mathematical model to predict temperature from dissolve time, along with an estimation as to how reliable the value can be.

Elizabeth showed us that salt dissolves too quickly to get reasonable resolution – so sugar was a good choice.

The results are reformatted in the graph and table here (right) that people without thermometers can use to convert dissolve times to temperatures.

How reliable is the most important question here, and our investigation suggests it is good to about 5 °C, though to achieve this accuracy, participants must follow the instructions closely. For example, use sugar not salt, use the right amounts of water and sugar, and stir at the recommended speed.



Time /s	Temp /°C
10	59
15	48
20	40
25	34
30	29
35	25
40	22
45	19
50	16
55	13
60	11
65	9
70	7
75	5
80	3
89	0

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