The weight of water

Weighing up whether or not to drink heavy water, Michelle Francl plunges into its history.

The small brown bottle has been sitting, unopened, on my desk for several weeks. I should just crack the seal and down the contents. But I can't quite bring myself to do it. After 40 years as a chemist, I can't bring myself to drink something that comes in a reagent bottle, no matter how curious I am — or my students are — to see if I can taste any difference between heavy water and distilled water.

It began in February's doldrums. We had discussed isotopic dilution in my honours general chemistry class, but just as class ended a hand shot up, "What would happen if you made your tea with heavy water?", "Nothing much, I imagine. I shouldn't even notice." But I had to admit, I was unsure of exactly what happened if you drank far more than that and promised to find out. The answer turned out to involve three mice, two dozen goldfish, and a handful of Nobel Prize winners experimenting on themselves, not to mention purported applications to interstellar travel and the elixir of life.

The story begins, coincidently, with a cup of tea. The Hungarian chemist (and future Nobel Laureate) George de Hevesy was visiting (recent Nobelist) Ernest Rutherford's lab in Manchester, England. One afternoon in 1913 he shared a cup of tea with Henry Moseley. Hevesy, who was spiking lead with radium to trace its metabolic route in plants, mused aloud to Moseley that he wished there was a way to track the individual water molecules in the tea through the body. The brilliant Moseley did not have high hopes that this could be achieved, but 21 years later, Hevesy managed the trick with some help from Harold Urey[1].

In 1934, Urey (soon to win a Nobel for his discovery of hydrogen's twin) sent Hevesy several litres of water enriched with 0.5% deuterium. Hevesy and his assistant Erich Hofer took 20 small goldfish (the total volume of goldfish was only 10 ml) and immersed them, for increasing periods of time, in 60 ml aliquots of the heavy water[2]. The overcrowded goldfish rapidly exchanged water with the deuterated water in the bowl, which became measurably less dense. Noting no change in the behaviour of the 0.2% deuterated goldfish (though how this might be assessed with so many goldfish stuffed into a small glass for up to 15 hours at time is unclear), Hevesy apparently concluded it was safe to drink the heavy water and proceeded to run the experiment he'd described to Moseley 20 years before. We don't know whether he, or Hofer, was the experimental subject, but one of them drank 100 ml and 250 ml samples of 0.46% enriched water, finally downing a full two litres to get the concentration of heavy water into the ppm regime[1]. They collected the subject's urine at intervals and distilled out the water to measure its density, doing more than a thousand distillations in the course of the work. Within twenty minutes of drinking the deuterated water, small amounts of heavy water showed up in the urine. Overall Hevesy and Hofer found water turns over far slower in humans than in goldfish; its half-life is just over nine days. They reported no ill effects and gave no hints about the taste of the water.

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In 1990, an assistant reactor operator essentially (and inadvisedly) repeated Hevesy and Hofer's experiment by spiking a twenty-litre cooler of juice in the lunchroom with a cup of heavy water pulled from the reactor's heavy water coolant line[3]. Eight co-workers drank the water before the contamination was discovered. It wasn't the taste of the adulterated juice that tipped them off, but random urine checks which picked up tritium produced in the heavy water when it was exposed to the neutrons in the reactor. Though he had intended the spiked juice to be nothing more than a prank, the unfortunate operator had to be taken into custody for his own safety and was eventually tried (and convicted) for the 'joke'.

A few months after Hevesy and Hofer's paper on heavy water in the human body appeared, Klaus Hansen, a professor at Oslo University, set out to test the toxicity of the newly discovered substance. In front of the press and attended by four doctors with stomach pumps and all the resuscitation equipment 1930s Norway could muster, Hansen swallowed a scant teaspoonful of heavy water[4]. Unsurprisingly, given Hevesy and Hofer's work, nothing untoward happened. Somewhat surprisingly, at least to Urey, he reported a 'dry burning sensation' after drinking the water. In response, Urey and his colleague at Columbia University, Gioacchino Failla, set up a blind taste test[5]. They each sampled one millilitre aliquots of pure D_2O and distilled H_2O, first swishing and spitting them like fine wines and, finally, swallowing a sample. They concluded that heavy water tastes the same as light water.

These were expensive experiments to run, and the amounts of heavy water available were limited. The heavy water Hansen reportedly consumed was worth almost $100,000 in current US dollars, and the total amount so negligible compared to the volume of water in the human body that Urey thought it a waste[4]. If you really wanted to know the effects on mammals, the water should have been given to something small, like a mouse, he suggested. That same year Gilbert Lewis at Berkeley did give a single white mouse less than one millilitre of pure heavy water[6]. The mouse behaved as if inebriated, compared to the two control mice, but otherwise appeared to suffer no ill effects. Because Lewis hadn't thought to collect any physiological data, the experiment didn't even provide as much information on the biological effects of deuteration on larger organisms as Hevesy and Hofer's work on goldfish (and themselves). The mouse trial did more damage to Lewis' reputation and to his relationship with the young Ernest Lawrence than it did to the mouse. Lawrence, who had been promised the heavy water that Lewis gave to the mouse as part of a deal to lure him from Northwestern to Berkeley, was reportedly irate that it had been squandered on a rodent, rather than given to a Nobelist-to-be[7].

Eventually, better-designed mouse experiments showed what Hevesy had intuited in his first paper on the biological effects of D_2O, that larger amounts carried risks due to the kinetic isotope effect. Henry Barbour and Jane Trace showed that replacing 40% of the water in a mouse is lethal[8], and the fuller analysis of the mouse models that Lewis lamented not having done was reported[9] in 1964. Fascinatingly, while many higher organisms, including plants, are intolerant to high doses of heavy water, some bacteria are impervious and can survive in 98% D_2O. In principle, these bacteria can be engineered to churn out fully deuterated proteins and other bioproducts, opening the door to interstellar travel and extending the human lifespan.

Though chemists don't often think about it, metabolic reactions in living organisms can fractionate isotopes. Some plants, such as rice and wheat, are depleted in C-13, and you can enrich water in D_2O by running it through barley mash[10]. Isotopic substitution can have a profound effect on human metabolic reactions as well, and the phenomenon is age dependent. In a speculative article, Xiyan Li and Michael Snyder hypothesize that treatment with heavy water could potentially be used to induce a metabolic slowdown which would trigger, or enhance, a state of hibernation, a step toward interstellar travel[11] (the molar volume change on freezing is positive, so heavy water will not prevent the cryogenic damage to cells owing to the expansion of water). Li and Snyder have observed in yeast models that heavier isotopes (including deuterium) become depleted in organisms with aging. They suggest it is possible that periodically supplementing the diet with appropriate isotopologues could extend human lifespans.

The further I dive into the literature, the more amazing the possible claims become. Short duration treatment in fruit flies increases their resilience to high temperatures[12]. Could enriching the diet in deuterium help stave off fevers, or will it enable us to better weather a hotter world? Would it slow down my lecture speed? Is that why my students are offering to fill up my water bottle? Mountebanks have been promoting heavy water as a panacea almost since the moment Urey isolated the first sample[13]. Even eminent chemists have not been immune. In a 1937 *Popular Science* article, chemist James Kendall opined[14] that the elderly might extend their lives by drinking heavy water, 'The heavy-water drinker's reactions would probably be slowed, and possibly his mental processes also, but who wants to be fast at sixty?' Sixty myself, I'm quite sure I wouldn't trade diminished mental acuity for a longer life. Still, Kendall retired at 70 and lived to almost 90, I wonder if he tried it. He noted it has a sweet taste.

In the end, I told my students that while there is no risk in a cup of tea made from heavy water, and that I should perhaps raise a cuppa to Hevesy, Hofer and Moseley in tribute, I still can't bring myself to taste it. Would you? ❐

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