Prince Rupert's Drops

In London at the end of the 17th century, scientific toys were popular. Fashionable among them were curious, tadpole-shaped glass drops—known in England as Prince Rupert's Drops—that already had been tantalizing both the scientific and nonscientific intelligentsia in Europe since at least 1625.

"This is to give notice that Drops known by the name of Prince Rupert's Drops are now made by Mr. Arthur Hewes and may be had at Mr. Jakemans at the Golden Still in the Old Bailey or at Mr. Goodwins Bookseller at the Queens-Head over against St. Dunstan's in Fleet Street," read an advertisement in an early October, 1695 edition of the *London Gazette.*

Procurement of these vitreous novelty items, which were sold in bottles (made presumably of normal glass), were followed by huddles of Londoners at pubs or around dinner tables whose participants then witnessed decidedly strange behavior for something as inanimate as glass. The antics of these little items were mystifying enough to have attracted the scientific attention of the early microscopist Robert Hooke who developed a partial explanation in the early 1660s.

Prince Rupert's Drops, so-named because the German prince presumably brought them to England, were made by letting molten drops of glass fall into cold water in which they would rapidly cool and solidify. Making them was hit or miss; many would disintegrate in the making. However, "Every one that Cracks not in the water and lies in it, till it be quite cold, is sure to be good," as Sir Robert Moray had recorded in 1661 when he was president of the then fledgling Royal Society in London.

Successfully made drops most often took the form of a glass teardrop tapered over one or several inches to a pointed end. The most brow-furling trait of these small glass structures, and for which they gained fame, was the ability of their heads to withstand hammer blows, yet, if the tail were broken with the gentlest of finger pressure, they explosively disintegrated.

The drops, known in Europe also as Holland Tears, were making rounds on such occasions as a dinner party on January 13, 1662 at the home of Samuel Pepys, the London diarist. This witty host apparently found the Royal Society's fuss over the drops worthy of satiric attention. In his 1663 poem "Hubridas," he wrote:

Honour is like that glassy bubble
That finds philosophers such trouble,
Whose least part crack'd the whole
does fly
And wits are crack'd, to find out why.

After the initial experiments by the Royal Society, Robert Hooke undertook his own set of more systematic studies with the drops. By encasing drops in fish glue, for example, he was able to trigger disintegration of the drops yet preserve the fracture pattern for observation through his microscopes. In his *Micrographia* (1665), Hooke provides a beautiful illustration of a drop with many linear cracks angularly radiating from what appears to be a central spine out to the drop's surface.

Hooke's theory, which has only been elaborated upon in recent years, held that the outermost portion of the drop solidifies more quickly than the interior leaving the inside in a state of tension so that the structure resembled an arch whose entire integrity vanishes if broken anywhere.

Isaac Newton found enough interest in the phenomenon and Hooke's explanation that, in his notes, he paraphrased Hooke: "soe that this drop being like an arched roof dissolves all into dust when the aequilibrium of pressure towards the center etc., is destroyed by braking the least snip of its tayle or scratching it." The metaphor of the arched roof suggests that Hooke and Newton both intuited that the surface was in a state of compression even as the interior was in a tensile state, a double-charged situation which later generations of scientists would use to explain the particularly catastrophic mode of the drops' disintegration.

About two centuries after Hooke registered his ideas, several French investigators entered the fray in the early 1870s. One of these authors, E. Peligot, added the idea that the startling hardness of the drops' surface could be related to the hardness of thermally tempered glass, which just then had been invented. William Thompson (Lord Kelvin), elaborated on previous studies by showing in 1889 that only a finite near-surface region of the drops had high strength. Yet not until the 1920s did A.A. Griffith provide the mathematical formulation for these qualitative ideas.

The exhibitionist fracture behavior of Prince Rupert's Drops could be explained more precisely in terms of microcracks that grow only so long as they are in a tensile environment like the inside of a drop and only so long as the product of the stress and the square of the crack's diameter exceed a certain threshold. Any intact drop has surface microcracks, but these initially are under compressive forces that prevent the cracks from expanding and propagating. Breaking a drop's tail, however, introduces a local tensile stress in the surface, or unleashes the tensile stress inside the drop, leading to a comprehensive network of cracks that speedily reduces the entire structure to rubble.

That explanation goes beyond Hooke's, but it was not detailed enough for Srinivasin Chandrasekar, a contemporary mechanical engineer at Purdue University, and M.M. Chaudhri of Cambridge University. In 1994, they published results from a series of high speed photography studies (frame rates of up to 500,000/s) of cracking drops whose aim was to reveal the detailed mechanisms of disintegration.

The data revealed that a crack initiated in the tail propagates in a series of fingerlike bifurcations at a velocity of up to 1900 m/s up to within the tensile zone of the drop's interior. Now that is detail that Hooke would have admired no end. Scanning electron micrographs of the rubble shows smaller fragments of the 100 μm range and flakelike fragments with dimensions roughly 10 times larger. The researchers speculate that a more extensive bifurcation pattern on the inside of the drops leads to the smaller particles. The cracking dynamics, the researchers note, is similar to the "self-propagating cracks in thermally tempered soda-lime glass blocks," providing a nod to Peligot who earlier had intuited connections between such glass and the drops.

Might the saga of Prince Rupert's Drops continue by swinging back from the scientific sector into the novelty and toy shops? These are different times than 1695 England. It is far easier to imagine the screams of joy by the lawyer who first hears about a commercial product that leaves behind tiny piles of wrecked glass than it is to expect bottles of Prince Rupert's Drops for sale at your local book store.

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FOR FURTHER READING: S. Chandrasekar and M.M. Chaudhri, *Philosophical Magazine* B, vol. 70, no. 6, pp. 1195–1218, 1994; L. Brodsely, C. Franck, and J.W. Steeds, *Notes and Recordings of the Royal Society of London*, vol. 41, pp. 1–26, 1986; C. Merret, trans., *The Art of Glass*, printed by A.W. For Octavian Pulleyn, at the Sign of the Rose in St. Pauls Church-yard, 1662.