Glass Flow?

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Early one spring morning in 1946, Clarence Hoke was holding forth in his chemistry class at West Side High School in Newark, New Jersey.

"Glass is actually a liquid." the North Carolina native told us in his soft Southern tones. "You can tell that from the stained glass windows in old cathedrals in Europe. The glass is thicker on the bottom than it is on the top."

Now, more than half a century later, that is the only thing I can actually remember being taught in high school chemistry. I didn't really believe it then, and I don't believe it now.

In the years that followed, I came across the same story every now and then. Most often it popped up in college textbooks on general chemistry. And now, thanks to the Internet, our Museum has received dozens of inquiries about whether or not this is true. Most people seem to want to believe it.

It is easy to understand why the myth persists. It does have a certain appeal. Glass and the glassy state are often described by noting their similarities with liquids. So good teachers, such as Mr. Hoke was, like to quote the story about the windows. As is the case with liquids, the atoms making up a glass are not arranged in any regular order and that is where the analogy arises. Liquids flow because there are no strong forces holding their molecules together. Their molecules can move freely past one another, so that liquids can be poured, splashed around, and spilled. But, unlike the molecules in conventional liquids, the atoms in glasses are all held together tightly by strong chemical bonds. It is as if the glass were one giant molecule. This makes glasses rigid so they cannot flow at room temperatures. Thus, the analogy fails in the case of fluidity and flow.

There are at least four or five reasons why the myth doesn't make sense.

Some years ago, I heard a remark attributed to Egon Orowan of the Massachusetts Institute of Technology. Orowan had quipped that there might, indeed, be some truth to the story about glass flowing. Half of the pieces in a window are thicker at the bottom, he said, but, he added quickly, the other half are thicker at the top. My own experience has been that for earlier windows especially, there is sometimes a pronounced variation in thickness over a distance of an inch or two on individual fragments. That squares with the experience of conservators and curators who have handled hundreds of panels. Although the individual pieces of glass in a window maybe uneven in thickness, and noticeably wavy, these effects result simply from the way the glasses were made. Presumably, that would have been by some precursor or variant of the crown or cylinder methods.

One also wonders why this alleged thickening is confined to the glass in cathedral windows. Why don't we find that Egyptian cored vessels or Hellenistic and Roman bowls have sagged and become misshapen after lying for centuries in tombs or in the ground? Those glasses are 1,000-2,500 years older than the cathedral windows.

Speaking of time, just how long should it take theoretically for windows to thicken to any observable extent? Many years ago, Dr. Chuck Kurkjian told me that an acquaintance of his had estimated how fast actually, how slowly glasses would flow. The calculation showed that if a plate of glass a meter tall and a centimeter thick was placed in an upright position at room temperature, the time required for the glass to flow down so as to thicken 10 angstrom units at the bottom (a change the size of only a few atoms) would theoretically be about the same as the age of the universe: close to ten billion years. Similar calculations, made more recently, lead to similar conclusions. But such computations are perhaps only fanciful. It is questionable that the equations used to calculate rates of flow are really applicable to the situation at hand.

This brings us to the subject of viscosity. The viscosity of a liquid is a measure of its resistance to flow the opposite of fluidity. Viscosities are expressed in units called poises. At room temperature, the viscosity of water which flows readily, is about 0.01 poise. Molasses has a viscosity of about 500 poises and flows like ... molasses. A piece of once proud Brie, left out on the table after all the guests have departed, may be found to have flowed out of its rind into a rounded mass. In this sad state, its viscosity, as a guess, would be about 500,000 poises.

In the world of viscosity, things can get rather sticky. At elevated temperatures, the viscosities of glasses can be measured, and much practical use is made of such measurements. Upon removal from a furnace, ordinary glasses have a consistency that changes gradually from that of a thick house paint to that of putty, and then to that of saltwater taffy being pulled on one of those machines you see on a boardwalk. To have a taffylike viscosity, the glass would still have to be very hot and would probably glow with a dull red color. At somewhat cooler temperatures, pieces of glass will still sag slowly under their own weight, and if they have sharp edges, those will become rounded. So, too, will bubbles trapped in the glass slowly turn to spheres because of surface tension. All this happens when the viscosity is on the order of 50,000,000 poises, and the glasses are near what we call their softening points.

Below those temperatures, glasses have pretty well set up, and by the time they have cooled to room temperature, they have, of course, become rigid. Estimates of the viscosity of glasses at room temperature run as high as 10 to the 20th power, that is to say, something like 100,000,000,000,000, 000,000 poises. Scientists and engineers may argue about the exact value of that number, but it is doubtful that there is any real physical significance to a viscosity as great as that anyway. As for cathedral windows, it is hard to believe that anything that viscous is going to flow at all.

It is worth noting, too, that at room temperature the viscosity of metallic lead has been estimated to be about 10 to the 11th power, (10^{11}) poises, that is, perhaps a billion times less viscous or a billion times more fluid, if you prefer than glass. Presumably, then, the lead caming that holds stained glass pieces in place should have flowed a billion times more readily than the glass. While lead caming often bends and buckles under the enormous architectural stresses imposed on it, one never hears that the lead has flowed like a liquid.

When all is said and done, the story about stained glass windows flowing just because glasses have certain liquid like characteristics is an appealing notion, but in reality it just isn't so.

Thinking back, I do recall another memorable remark by Mr. Hoke. One day, our self appointed class clown sat senselessly pounding a book on his desk at the back of the room. "Great day in the mawnin', son!" shouted Hoke. "Stop slammin' your book on the desk. Use your head!" That was good advice no matter how you read it.