Viscosity is the resistance of a fluid to flow. For pure liquids, viscosity increases with molecule size and decreases with temperature. The viscosity of mixtures also depends on the fraction of volume occupied by larger molecules or particles (the "dispersed phase") present according to our equations of the week:

$$\eta = \eta_0 f(\phi) \qquad \phi = \frac{V_{\text{dispersed}}}{V_{\text{total}}}$$

where η is the viscosity of the solution, η_0 is the viscosity of the pure continuous phase, $f(\phi)$ is a function that increases with ϕ, $V_{\text{dispersed}}$ is the volume occupied by non-solvent molecules, and V_{total} is the total volume of the solution. Typically, $\eta \approx \eta_0$ for $\phi < 0.5$.

A number of approaches exist for measuring viscosity. In lab this week, you'll measure the viscosity of milkshakes by determining the speed at which a ball bearing to falls through them. Professionals use tools like rheometers and capillary viscometers to measure viscosity. Many techniques are also useful for determining relative but not absolute viscosity, including measuring the flow rate through a funnel or measuring the spreading of the fluid on a surface.

Viscoelasticity

When a fluid experiences a sudden stress, it initially deforms elastically like a solid, following the equation $E = \sigma/\epsilon$ from week four: only after the molecules have had a chance to begin moving around one another (a time period called the relaxation time, τ) does the fluid begin to flow. For small stresses and low-viscosity liquids like water, τ is typically too small to notice. However, very viscous liquids like cornstarch with long relaxation times or large, sudden stresses (like a belly-flop off a diving board) can produce elastic deformations visible to the naked eye.

When a fluid is cooled, the relaxation time grows longer and longer as molecules lose the kinetic energy required to move around one another. If the molecules in a solution are very large or densely-packed, they may become trapped in place during cooling as the relaxation time increases indefinitely, producing a glass. Although a glass is a type of solid, its molecules do not have an ordered arrangement like those in a crystal. Hard candies like Bill Yosses' candy apples are a common culinary example of glasses.

Increasing viscosity during cooking

Nathan Myhrvold describes four major approaches for increasing the viscosity of fluids during cooking:

1. Reduction: Evaporating off water concentrates the molecules left behind (but often sacrifices volatile aromas)
2. Forming Emulsions: At sufficiently high volume fraction, droplets of an immiscible fluid (e.g., oil into water) act like very large particles to increase viscosity
3. Adding Starch: Starch granules (found in flour, corn, potato, and rice) swell with water on heating to occupy a large volume fraction, increasing viscosity
4. Adding Modernist Thickeners: Long polymers occupy large effective volumes due to random coiling, taking up large volume fractions without significantly impacting flavor. (Examples include xanthan gum, alginate, and methylcellulose.)

Science Review Questions

1. Molasses candy is made by pouring molasses onto snow; after a few seconds, the molasses can be picked up and eaten. What type of solid is molasses candy?
   (a) Crystal
   (b) Glass
   (c) Gel

2. Boston is the site of the Great Molasses Disaster, a flood of molasses unleashed on the North End by a rupturing tank in January 1919. How would the speed of the traveling 3 m-tall molasses wave have been different if the disaster had occurred in July?
   (a) Slower in July
   (b) No Difference
   (c) Faster in July

3. Ketchup flows slowly when you first turn the bottle upside down, but then flows too quickly when you shake the bottle. What type of liquid is ketchup?
   (a) Shear thinning
   (b) Newtonian
   (c) Azeotropic
   (d) Shear thickening

4. Polymer A has twice as many repeating units as polymer B. How much more volume does polymer A effectively occupy than polymer B?
   (a) Twice as much
   (b) $2^{3/2} \approx 2.8$ times as much
   (c) Eight times as much

5. Butter is an emulsion of water droplets in butterfat at a volume fraction of ϕ_B=0.2. Why does butter retain its stick shape in the fridge?
   (a) Its viscosity is so high that it does not flow noticeably.
   (b) Butterfat is solid at room temperature.

6. "I Can't Believe It's Not Butter" has half the calories of regular butter. Which is the most likely value for ϕ_{ICBINB}, the volume fraction of water in this product?
   (a) 0
   (b) 0.2
   (c) 0.4
   (d) 0.8
   (e) 1