Using Visuals to Help Explain Tonicity to Introductory Biology Students

Brian Rafferty, Lalitha Jayant

Abstract

The inability of students to properly understand the principles underlying osmosis and tonicity leads to misconceptions that further impair their ability to apply these concepts to physiological situations. We describe a simple and inexpensive visual exercise using beads and water to mimic solutions. Using these model solutions, students will understand the concepts of tonicity and osmolarity. The hands-on exercise is supplemented with a worksheet that reinforces the concepts they learned in doing the activity. This exercise has broad application with respect to both the level of students targeted and the courses in which it can be utilized, and it is flexible enough to personalize for each situation.

Key Words: tonicity; osmolarity; visual; worksheet; hands-on; high school; college.

Introduction

Osmolarity and tonicity are challenging concepts for students in introductory biology courses to understand, even if they are science majors. This topic is extremely important for students to comprehend, as these are two related yet different concepts. Misconceptions surrounding osmosis have persisted for decades, specifically those involving tonicity and water movement (Odum, 1995; Fisher et al., 2011). Definitions of osmolarity and tonicity differ among textbooks (Vujovic et al., 2018), and while any of these definitions may be sufficient for instructor understanding, this can add to student confusion. We clarify the two concepts and their distinctions for students as follows.

Osmolarity is defined as the number of milliosmoles (mOsm) of solute in 1 L of solution or the concentration of solute particles in 1 L of solution, represented as mOsm/L or mOsm (Urry et al., 2017). Osmolarity is deemed a colligative property in the chemistry field (Jespersen et al., 2015) and, as such, students must be made aware that it is the total concentration of nonpenetrating solutes that matters, not the composition of those solutes, in terms of osmolarity. Tonicity is defined as the ability of a solution surrounding a cell to cause that cell to gain or lose water (Urry et al., 2017). While osmolarity is an absolute quantity, tonicity is relative.

Another point to keep in mind is that because osmolarity takes into account the concentration of both penetrating and nonpenetrating solutes, we must be clear that assignment of tonicity is derived only from the nonpenetrating solute concentrations (Vujovic et al., 2018). Solutes that are unable to cross a membrane, whether real or artificial, are termed nonpenetrating, while those solutes that have a mechanism for transport are termed penetrating. When comparing two solutions on either side of a semipermeable membrane, the solution with higher nonpenetrating solute concentration is termed hypertonic, while the one with lower nonpenetrating solute concentration is hypotonic. If two solutions have the same concentration of nonpenetrating solutes, they are considered isotonic. Note that the emphasis in naming these solutions is based on the solute concentration, not the concentration of free water in each solution. However, when two solutions with nonpenetrating solutes are compared, students are taught that because of osmosis, water will move from the hypotonic solution to the hypertonic solution, and that this process is passive, with no energy requirements. Many students fail to see that a hypotonic solution has more water (solvent) than a hypertonic solution and regularly conclude that water moves from the hypertonic solution to the hypotonic solution. Let’s take a simple question such as “What will happen to the cell mass or volume if a cell with an internal concentration of 0.9% solute concentration is placed in a solution of 1.5% solute concentration?” Students typically answer that water will move into the cell and the cell will burst. They argue that the solution outside the cell has a higher solute concentration than that inside the cell. To remove this misconception, we have devised a simple exercise to help students...
understand the concepts of osmolarity, tonicity, and direction of water movement due to osmosis.

**Exercise Description**

The goal of this exercise is to allow students to visualize the amount of solute and the amount of water present in a solution, to help them make valid predictions of water movement due to osmosis. The solute for this experiment can be any small, circular plastic bead that does not absorb or retain water. Students are asked to make 10% and 20% bead solutions in a total volume of 100 mL using graduated cylinders. After completing questions 1–7 of the worksheet (see Appendix S1 in the Supplemental Material available with the online version of this article), each student/group weighs 10 g and 20 g of beads and places them in 100 mL graduated cylinders labeled “10%-1” and “20%-1” (Figure 1A). The students then pour water into both cylinders accurately to make a 100 mL bead solution, watching the lower meniscus (Figure 1B). Next, using a funnel whose flute is smaller than the size of the beads, they carefully transfer the water from “10%-1” into another measuring cylinder labeled “10%-2,” taking care not to spill even a drop of water (Figure 1C). (Note: None of the beads should fall into the second measuring cylinder.) This process is then repeated with the 20% solution, and the new cylinder with water only is labeled “20%-2”.

Students are then asked to note the volume of water in the new measuring cylinders and answer questions 8 and 9. To bring the exercise back to the measurement of osmolarity and its use to determine tonicity, students are asked to complete questions 10–12. The students’ answers to questions 11 and 12 can inform the instructor as to whether the students have been able to grasp the relationship of osmolarity to tonicity and the expected movement of water with respect to osmosis.

**Summary**

This exercise helps simplify a biological and chemical concept that high school and college students (both majors and nonmajors) find challenging and have various misconceptions about (Odom & Barrow, 1995, 2007), while requiring very little in the way of supplies and allowing for flexibility. It can be used in high school classrooms as well as in college biology and chemistry courses for majors or nonmajors. We currently use this exercise as a primer for our osmosis lab, which involves monitoring change in a mass of artificial cells, created with a semipermeable synthetic membrane, in response to differences in solute concentrations between the cell and its environment. In this case, we use the different cylinders to model the solutions inside and outside the cell to help the students predict expected changes in the mass of the cells. The simplicity of the setup can lend itself to modeling more complex solutions, such as blood or filtrate in the kidney, using beads of different colors to represent various penetrating and nonpenetrating solutes. This exercise will make an excellent addition to all kinds and levels of biology courses taught both in high school and undergraduate colleges.

**Supplemental Material**

- Appendix S1: Worksheet
- Appendix S2: Answer Key

**References**

Fisher, K.M., Williams, K.S. & Lineback, J.E. (2011). Osmosis and diffusion conceptual assessment. *CBE–Life Sciences Education*, 10, 418–429.
Jespersen, N.D., Hyslop, A. & Brady, J.E. (2015). *Chemistry: The Molecular Nature of Matter*, 7th ed. Hoboken, NJ: Wiley.

Odom, A.L. (1995). Secondary & college biology students’ misconception about diffusion and osmosis. *American Biology Teacher, 57*, 409–415.

Odom, A.L. & Barrow, L.H. (1995). Development and application of a two-tier diagnostic test measuring college biology students’ understanding of diffusion and osmosis after a course of instruction. *Journal of Research in Science Teaching, 32*, 45–61.

Odom, A.L. & Barrow, L.H. (2007). High school biology students’ knowledge and certainty about diffusion and osmosis concepts. *School Science and Mathematics, 107*, 94–101.

Urry, L.A., Cain, M.L., Wasserman, S.A., Minorsky, P.V. & Reece, J.B. (2017). *Campbell Biology*, 11th ed. New York, NY: Pearson.

Vujovic, P., Chirillo, M. & Silverthorn, D.U. (2018). Learning (by) osmosis: an approach to teaching osmolarity and tonicity. *Advances in Physiology Education, 42*, 626–635.

**BRIAN RAFFERTY** (brafferty@bmcc.cuny.edu) is an Assistant Professor and **LALITHA JAYANT** is a Professor in the Science Department, Borough of Manhattan Community College, New York, NY 10007.