Acidity and the Henderson-Hasselbalch Equation
ONEXYS Read-ahead

Introduction

The pH scale measures the acidity of a solution. The scale ranges from 0 to 14, with a perfectly neutral solution having a pH of 7.0. Low pH values signify acidity and high pH values signify alkalinity. Vinegar (acetic acid), for example, has a pH of about 2.4, while the sulfuric acid in a car battery has a pH of 0.8.

Figure 1: Acetic acid

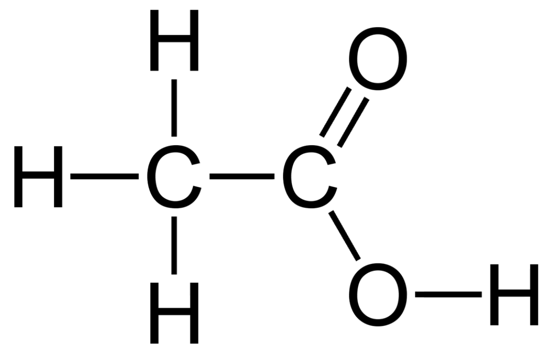

Figure 2: Molecular structure of acetic acid

In the following questions, we will use logarithms and the Henderson-Hasselbalch equation to explore the concept of acidity in more depth.

Instructions

After reading through the *Acidity and the Henderson-Hasselbalch Equation* context and questions below, you should complete the application reflection in Canvas. Note: *you will have a chance to talk further with your coach before answering the questions below in detail*. The point of the pre-read is to "prime the pump" for further conversations with your coaches.

Acidity and the Henderson-Hasselbalch Equation

A related measurement of acidity, pK_a, gives the acidity of a certain hydrogen atom in a given molecule. This constant is related to the acid dissociation constant, which measures how often a molecule will be protonated. (Protonation is the addition of a proton to an atom, ion, or molecule to form the conjugate acid.) It is important to note that pK_a for a given hydrogen atom in a given molecule is *fixed*, unlike pH, which is dependent the concentration of the molecule in the solution.

The pK_a of an acid is the pH at which the acid is exactly half-dissociated. This relationship follows from an equation, discovered by scientists Lawrence Henderson and Karl Hasselbalch, called the Henderson-Hasselbalch equation. In this equation, shown below, A^- represents the deprotonated form of the acid, while HA represents the protonated form. The brackets around A and HA signify (molar) concentration.

$$\text{pH} = \text{p}K_a + \log_{10}\left(\frac{[\text{A}^-]}{[\text{HA}]}\right)$$

pH often needs to be within a certain range for a biological process to be carried out. A healthy body, for example, sits at a slightly basic pH of 7.4, a pH at which many biological processes are optimized.

Questions

Note that Questions 2 and 3 are related, as are Questions 4 and 5.

1. (Graded for completeness only.) Explain how the statement "The pK_a of an acid is the pH at which the acid is exactly half-dissociated" follows from the Henderson-Hasselbalch equation

$$\text{pH} = \text{p}K_a + \log_{10}\left(\frac{[\text{A}^-]}{[\text{HA}]}\right).$$

   Hint: "half-dissociated" means that half of the molecules are in the deprotonated form A^- and half are in the protonated form HA.
2. A new animal species, the philosoraptor, has a tough, leathery skin that can withstand a minimum acidic pH of 4.0; in pH environments more acidic than 4.0, the philosoraptor's skin will wear away and it will die. Not the brightest of creatures, Earl the philosoraptor decides to wade into a lake of itaconic acid, which has a pK_a of 3.8. If the protonated (HA) concentration of the acid is 3.0×10^{-6} M, and the deprotonated (A-) concentration is 2.0×10^{-6} M, what is the pH of the lake? Round your answer to two decimal places.
3. What is the minimum ratio of deprotonated to protonated concentrations of itaconic acid necessary for Earl the philosoraptor to survive in the lake? Round your answer to two decimal places.
4. A recent contamination of Lake Oswego by an unknown acid saw the pH fall to 2.5. Given that the concentration of HA is 3.0×10^{-3} M, and the concentration of A- is 4.0×10^{-4} M, find the pK_a of this unknown acid.
5. Given the pK_a you computed in Question 4, what is the most likely candidate for the unknown acid? (You will likely need to do an internet search to answer this question.)
6. Suppose you are making pickles by soaking cucumbers in a brine consisting primarily of vinegar. From past experience, you know that the pH of the brine should be between 1.5 and 3.5. Vinegar (acetic acid) has a pKa of 4.75. If the concentration of the protonated form (HA) is 1.0×10^{-1} M, find the necessary range of concentrations of the deprotonated form (A-). Give your answer in the form of a lower bound and an upper bound, both rounded to two significant digits.

Instructions, part deux

After reading and reflecting on these questions, complete the application reflection on Canvas. This will give your coach some insight on your thinking in order to best help you before you are required to formally answer these questions.