dissolved substances (for example, from your boots or feet) would make the water in such a situation a relatively good conductor. It is always best to assume that electricity is dangerous around water!

8.2 pH OF A SOLUTION

PRACTICE

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Understanding Concepts

1. Examples of products with specified pH values include skin creams, soils, shampoos, cat foods, wines, water (in rain, wells, lakes, rivers, aquariums), and waste water outflows.
2. $[H^+_{(aq)}]$ values are:
   (a) 1×10^{-11} mol/L
   (b) 1×10^{-2} mol/L
   (c) 1.0×10^{-4} mol/L
   (d) 1.0×10^{-14} mol/L
3. pH values are:
   (a) 3.0
   (b) 5.0
   (c) 7.00
   (d) 10.00
4. $[H^+_{(aq)}]$ values would have to change from 1×10^{-5} mol/L to 1×10^{-7} mol/L: a ratio of 100:1. The hydrogen ion concentration would have to decrease by a factor of 1/100.
5. Since $\log 1 = 10^0$ exactly, by the definition of logarithms, the pH of a solution with a hydrogen ion concentration of 1 mol/L will be 0.0.

   Note: Since the concentration is given to one significant digit, the pH is reported to one decimal place (one place in the logarithm characteristic).
6. (a) $v_{H^+} = 100$ L

   $C_{H^+} = 1 \times 10^{-3}$ mol/L

   $$n_{H^+} = 100\ \cancel{L} \times \frac{1 \times 10^{-3}\ \text{mol}}{1\ \cancel{L}}$$

   $$n_{H^+} = 0.1\ \text{mol}$$

   The amount of hydrogen ion present in the wine is 0.1 mol.

   (b) $v_{H^+} = 100$ L

   pH $= 8.00$

   $C_{H^+} = 1.0 \times 10^{-8}$ mol/L

   $$n_{H^+} = 100\ \cancel{L} \times \frac{1.0 \times 10^{-8}\ \text{mol}}{1\ \cancel{L}}$$

   $$n_{H^+} = 1.0 \times 10^{-6}\ \text{mol} = 1.0\ \mu\text{mol}$$

   The amount of hydrogen ion present in the seawater is 1.0 mmol.

   (c) $v_{H^+} = 100$ L

   $C_{H^+} = 10.0$ mmol/L $= 0.0100$ mol/L

   $$n_{H^+} = 100\ \cancel{L} \times \frac{0.0100\ \text{mol}}{1\ \cancel{L}}$$

   $$n_{H^+} = 1.00\ \text{mol}$$

   The amount of hydrogen ion present in the stomach acid is 1.00 mol.

Reflecting

7. (a) No, setting a zero measured level would have to specify the precision of the zero measurement. A more precise technology may turn an earlier measurement of zero into a non-zero value. Secondly, every chemical is toxic at some concentration. There is no known chemical that needs to be reduced in concentration to zero (whatever that means) in order to become non-toxic.

(b) Theoretically, a zero level would mean no entities (atoms, molecules, and/or ions) of the chemical present at all. Empirically, there would be no way of confirming or refuting a theoretical level of zero. Although a theoretical level of zero is possible, it is not probable, and, again, is impossible to test.

(c) A zero level is not measurable; a zero reading may always be taken to mean that the quantity of chemical is just too low to be detected by the instrument. A measurable zero quantity is a contradiction in terms: it would require a perfect measuring device and/or system.

(d) One possible answer: A limit should be set low enough so that there are no measurable effects from such a level, even over a lengthy period of time.

Note: How long a time? Ahhh, now there's a good point for discussion and opinion. ... The world becomes a very much trickier place the moment students wrap their minds around the concept that there is no such thing as "perfectly" safe.

PRACTICE

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Understanding Concepts

8. Solution pH is measured with pH paper, with indicators, and with pH meters.
9. (a) Pure water has a pH of 7.
   (b) The hydrogen ion concentration of pure water is 10^{-7} mol/L.
10. (a) The calculation of values to complete spaces in Table 2 are, in order:

Oranges

$$\begin{aligned} pH &= -\log [H^+_{(aq)}] \\ &= -\log [5.5 \times 10^{-3} \text{ mol/L}] \\ pH &= 2.26 \end{aligned}$$

Asparagus

$$\begin{aligned} [H^+_{(aq)}] &= 10^{-pH} \\ &= 10^{-8.4} \\ [H^+_{(aq)}] &= 4 \times 10^{-9} \text{ mol/L} \end{aligned}$$

Olives

$$\begin{aligned} [H^+_{(aq)}] &= 10^{-pH} \\ &= 10^{-3.34} \\ [H^+_{(aq)}] &= 4.6 \times 10^{-4} \text{ mol/L} \end{aligned}$$

Blackberries

$$\begin{aligned} pH \quad & 5\ -\log [H^+_{(aq)}] \\ & 5\ -\log [4\ 3\ 10^{-4} \text{ mol/L}] \\ pH \quad & 5\ 3.4 \end{aligned}$$

(b) Based on pH values only, oranges are the most acidic, and should have the most sour taste.

Making Connections

11. Answers should *always* present both sides of the risk/benefit concept. An example might be the use of acidic cleaners to remove rust stains from plumbing fixtures. The aesthetic benefit of shiny plumbing fixtures carries with it the risk of skin irritation or disfiguring marking of other surfaces, resulting from careless use of the acidic cleaner; and disposal might be a problem if the cleaner is not greatly diluted.

SECTION 8.1–8.2 QUESTIONS

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Understanding Concepts

1. (a) $[H^+_{(aq)}] = 1 \times 10^{-3}$ mol/L for the fruit juice, and 1×10^{-12} mol/L for the household cleaner.

(b) The hydrogen ion concentration ratio, juice to cleaner, is

$$\frac{1 \times 10^{-3}\ \cancel{\text{mol/L}}}{1 \times 10^{-12}\ \cancel{\text{mol/L}}} = \frac{1 \times 10^{9}}{1}, \quad \text{or a billion to one.}$$

2. (a) pH $= 8.0$

(b) pH $= 7.0$

(c) pH $= -\log [H^+_{(aq)}]$

$= -\log [2.5 \times 10^{-6}$ mol/L]

pH $= 5.60$

(d) pH $= -\log [H^+_{(aq)}]$

$= -\log [1.3 \times 10^{-4}$ mol/L]

pH $= 3.89$

3. (a) Pickling vinegar is more acidic.
(b) Pickling vinegar has a higher hydrogen ion concentration.
(c) $[H^+_{(aq)}] = 10^{-pH}$

$= 10^{-2.4}$ mol/L

$[H^+_{(aq)}] = 4 \times 10^{-3}$ mol/L (standard vinegar)

$[H^+_{(aq)}] = 10^{-pH}$

$= 10^{-2.2}$ mol/L

$[H^+_{(aq)}] = 6 \times 10^{-3}$ mol/L (pickling vinegar)

4. (a) The hydrochloric acid has a lower pH because the molecules ionize to a much greater extent than the acetic acid.

(b) $HCl_{(aq)} \xrightarrow{>99\%} H^+_{(aq)} + Cl^-_{(aq)}$

$HC_2H_3O_{2(aq)} \xrightarrow{<50\%} H^+_{(aq)} + C_2H_3O^-_{2(aq)}$

(c) The $HCl_{(aq)}$ should be handled more carefully because it will react much faster, and so is more dangerous.

5. (a) $[H^+_{(aq)}] = 10^{-10}$ mol/L (pH paper)

Note: When a pH value has *no* digits in the characteristic at all, it represents a quantity that is known only to an order of magnitude—that is, a quantity with *no* significant digits; where only the place value is known. This level of certainty is fairly common when pH is measured with coarse-scale pH papers. Measured values with no significant digits, or even those with only one significant digit, are rare. They seldom occur outside of systems like pH, that have such a great range that logarithmic scales must be used to express them.

(b) $[H^+_{(aq)}] = 10^{-pH}$

$= 10^{-9.8}$ mol/L

$[H^+_{(aq)}] = 2 \times 10^{-10}$ mol/L (pH paper or pH meter)

(c) $[H^+_{(aq)}] = 10^{-pH}$

$= 10^{-9.84}$ mol/L

$[H^+_{(aq)}] = 1.4 \times 10^{-10}$ mol/L (pH meter)

(d) $[H^+_{(aq)}] = 10^{-pH}$

$= 10^{-9.836}$ mol/L

$[H^+_{(aq)}] = 1.46 \times 10^{-10}$ mol/L (very precise pH meter)

6. (a) $[H^+_{(aq)}] = 10^{-pH}$

$= 10^{-5.4}$ mol/L

$[H^+_{(aq)}] = 4 \times 10^{-6}$ mol/L

(b) $[H^+_{(aq)}] = 10^{-pH}$

$= 10^{-5.72}$ mol/L

$[H^+_{(aq)}] = 1.9 \times 10^{-6}$ mol/L

(c) pH $= -\log [H^+_{(aq)}]$

$= -\log [5 \times 10^{-7}$ mol/L$]$

pH $= 6.3$

(d) pH $= -\log [H^+_{(aq)}]$

$= -\log [7.9 \times 10^{-6}$ mol/L$]$

pH $= 5.10$

Applying Inquiry Skills

7. **Experimental Design**

   Each of six samples of solutions of different acids, of equal concentrations, will be tested for conductivity, to determine which are strong acids.

   Note: Alternatively, pH paper, indicators, or a pH meter could also be used.

8. **Prediction**

   Since a change in hydrogen ion concentration of 100 times (or 10^2) represents two pH units, it seems probable that when 1.0 mL of vinegar is diluted 100 times, the pH (characteristic) will increase by 2.

   Experimental Design

   The pH of some 5% V/V household vinegar is measured to one place in the mantissa (i.e., one decimal place). A 1.0-mL sample of the household vinegar is diluted to 100 mL, and the pH of the diluted sample is measured.

   Materials

   - household vinegar (5% V/V acetic acid)
   - wash bottle of pure water
   - 10-mL graduated cylinder
   - 250-mL graduated beaker
   - stirring rod
   - pH meter (or pH paper, precise to 0.1 unit)

   Procedure

   1. Measure and record the pH of some household vinegar.
   2. Obtain 1.0 mL of the vinegar in the 10-mL graduated cylinder.
   3. Use a wash bottle to rinse the vinegar sample into the beaker.
   4. Add pure water to the beaker until the solution volume is 100 mL.
   5. Measure and record the pH of the diluted vinegar.

   Evidence

   The pH of the initial vinegar sample is 2.4.
   The pH of the diluted vinegar sample is 3.4.

   Analysis

   The volume to which 10 mL of vinegar must be diluted in order to increase its pH by two units is more than 1000 mL. The pH value only changed by about 1, indicating that although the acid solution concentration was decreased 100 times, the hydrogen ion concentration seems to have decreased only about 1×10^1, or 10 times.

Evaluation

The experimental design is judged to be adequate because the experiment produces the evidence needed to answer the (very simple) question with a high degree of certainty (even though the Prediction was found to be incorrect).

The procedure is also judged adequate because the steps are simple and clear.

The technological skills of the experimenter are judged adequate — no special skills are required, and the procedure is very straightforward.

The results have a very high degree of certainty. None of the materials or procedure steps are likely to have any unexpected uncertainty. The percentage difference cannot be calculated as such, but the answer differs from the prediction by at least an order of magnitude.

The prediction is definitively falsified because the evidence is clearly different from the prediction.

The assumption (that the pH value varies proportionally with the negative of the logarithm of the concentration of a weak acid) is not supported by the results of this experiment. It seems likely that there is a more complex relationship between weak acid concentration and hydrogen ion concentration than was assumed.

Note: This is a nice example of a case where a simple concept turns out to be more complex — offering an opportunity to have students learn by falsifying a prediction. Students' only experience with dilution and pH to this point is with the strong acid $HCl_{(aq)}$ (Investigation 8.2.1,) and from calculations involving strong acids. Students will normally form predictions based upon the $pH = -\log[H^+_{(aq)}]$ equation, or upon their experience from Investigation 8.2.1. Neither of these methods is useful when dealing with a weak acid, where the varying degree of ionization is a predominant factor. Empirically (experimentally), the final volume (100 L or more) is required to change the vinegar concentration by two pH units. A theoretical explanation comes in Chemistry 12.

9. The design is probably valid because toothpaste is diluted in your mouth as you brush, anyway — so the pH measured will be approximately correct. An alternative design might be to squeeze toothpaste directly onto pH paper strips.

Making Connections

10. Examples of possible Did You Know?:

Some plants are acid-loving and others are not. For example, evergreen trees are acid-loving: they grow best in soil that has a pH of less than 7 and will actually change the pH of the soil in which they grow. If you remove an evergreen tree from a lawn and plant grass in that area, the grass probably won't grow: grass is not acid-loving. The soil will have to be neutralized by adding a base, such as lime, to the soil.

Flowers on some plants will change colour depending on the pH of the soil. Examples are rhododendrons and azaleas, which are acid-loving but vary in colour depending upon the soil pH. The pH can be decreased into the acidic range by adding citric fruit peels, pine needles, and peat moss to the soil.

Some vegetables, such as cabbage, cauliflower, broccoli, and turnips, like to grow in alkaline soil with a pH of 7.5-8.0. Horticultural lime is used by gardeners to "sweeten" the sour soil.

You can test a sample of your soil with pH paper or a pH meter, or take the soil sample to a nearby greenhouse.

11. An acid wash will clean the lettuce and also tend to remove pesticides and kill microorganisms on it. The likely acid to use would be the one that is commonly edible: acetic acid. You can use a diluted vinegar wash in your sink or in a spray bottle.

Reflecting

12. "Weak," referring to acids, indicates the degree of ionization in water. It has nothing necessarily to do with concentration.