Electrical Conductivity

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The term pH, being very important in chemistry and biology, is widely known even to the general public, and advertisers often describe products, such as shampoos, as pH-balanced. A less well known but almost as useful term is *electrical conductivity* (EC), a measure of the electric current that a solution carries. EC and pH are similar in that both are used to measure ion concentration, but they differ in that pH is a measure of hydrogen-ion concentration, and EC serves as an estimate of the total ion concentration. EC is therefore useful because it is directly proportional to the ion concentration of a solution. Ions are positively or negatively charged molecules or atoms. Many substances dissociate into ions when dissolved—for example, sodium chloride (NaCl, or table salt) forms sodium (Na^+) and chloride (Cl^-) ions when dissolved in water. Positive ions are called cations; negative ions are anions. (To remember the difference between a cation and an anion, mentally associate the *t* in cation with the similarly shaped addition symbol). Some chemicals, such as table sugar, dissolve in water but do not ionize.

Units of Measure

Unlike pH, which is not written in terms of units of measurement, EC is expressed in units, such as Siemens/m (S/m). Siemens replaces the old unit, mho, which is pronounced like Moe of the Three Stooges. As is typical of many measurements, there are a multitude of units in use. Some units and their equivalents are: 1 mmho/cm = 1000 μmho/cm = 1mS/cm = 1000μS/cm = 1 dS/m = 0.1 S/m.

Applications

EC is widely used to quickly estimate the ionic or soluble-salt concentration in soils, water supplies, fertilizer solutions, and chemical solutions. Water deionization systems often have a small in-line EC meter with an electric light bulb that indicates system status. Water continuously flows through the in-line EC meter, which is designed so that when the water is very pure (low ion concentration and low EC), electricity flows through the circuit and illuminates the bulb. When the water contains more ions, the bulb goes dark because the pathway of least resistance for the electricity is now through the ion-rich water. The measurement is fast and simple.

Instrumentation

For class use, a pocket EC meter (Hershey 1988) is ideal (figure 1). Many scientific supply companies sell pocket EC meters for about $50. (The μ-Sensor 4 pocket EC meter with automatic temperature compensation is available for $45.00 from Whatman Labsales, 1-800-942-8626.) These meters have a liquid crystal display (LCD) and are powered by four button batteries. To standardize the meter, purchase a potassium chloride solution or prepare one using reagent grade KCl, distilled water, and a volumetric flask. A 10-mM KCl solution has an EC of 1.4 dS/m at 25°C. Pocket meters are standardized by immersing the electrodes at the base of the meter into a KCl standard and adjusting the LCD to read the appropriate value by turning a recessed screw in the back of the meter.

Be careful not to get the top half of the meter wet because water may get inside the meter and damage

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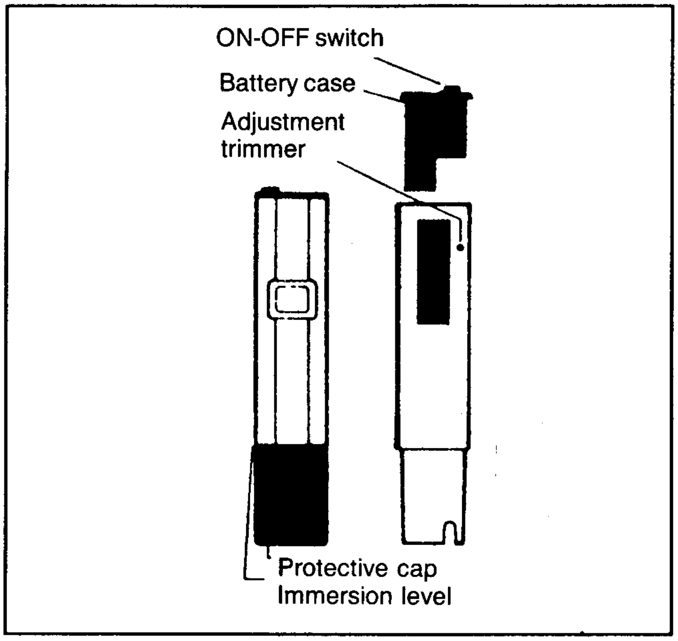

Figure 1. Drawing of a pocket EC meter. Height, 14 cm; width, 3 cm; depth, 1.5 cm.

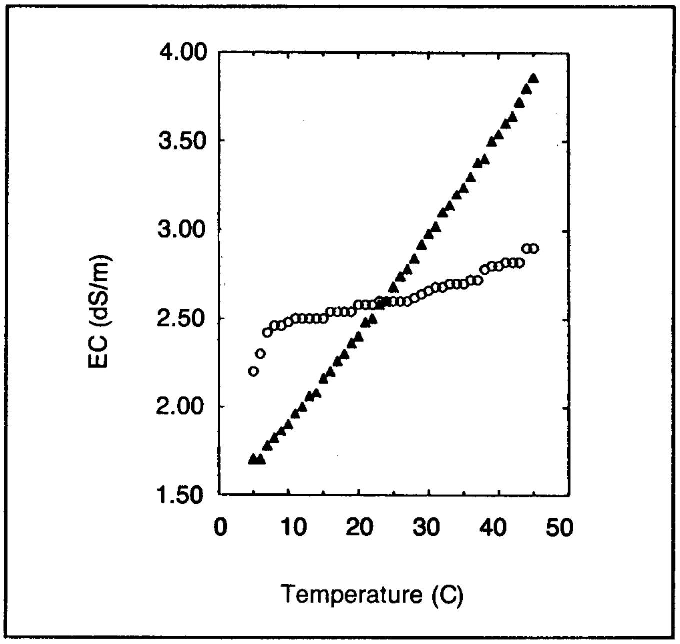

Figure 2. EC of 20 mM KCl as measured with pocket EC meters with or without automatic temperature compensation (ATC). From Sand and Hershey 1990.

the electronic components. If water does get inside, the meter will not function properly. However, if the inside is allowed to dry, the meter may work properly.

Pocket EC meters read in units of μS/cm when the LCD reading is multiplied by 100. To avoid this cumbersome multiplicaton step, use a permanent felt marker to place a decimal point between the two rightmost digits. The LCD will then read directly in mS/cm or dS/m. The latter unit is preferable because the international system of units (SI) requires that a base unit occur in the denominator.

The *Journal of Chemical Education* has published many designs for homemade EC meters (Battino 1991; Havrilla 1991; Mercer 1991; Vitz 1987). The simplest is made from two straightened paperclips, a rubber stopper, and a 9-volt battery (Williams 1985). The EC is roughly proportional to the rate of bubble formation at the paperclip electrodes. Slightly more sophisticated EC meters are made with a 9-volt battery, wire, resistor, and light-emitting diode (LED) (Gadek 1987; Russo 1986). The higher the EC, the brighter the LED. However, most of the homemade EC meters are semiquantitative, at best, so they are not as desirable for teaching use as the commercially available pocket EC meter.

Temperature Dependence

The EC of a solution is strongly temperature dependent, so EC is reported at a standard temperature of 25°C. Figure 2 shows how EC varies widely with temperature when an uncompensated EC meter is used. Fortunately most pocket EC meters now have automatic temperature compensation, which helps eliminate most of the temperature dependence over a fairly wide range.

EC of Common Substances

Have elementary-level students bring in common liquids for EC measurement. Samples for EC measurement include water from a local supply, fertilizer solutions, foods, and beverages (table 1). Mineral waters, such as Perrier, have a measurable EC because of the ions they contain. Milk has an EC higher than other beverages because of its sodium content. People who have been placed on low-salt diets should definitely avoid high-EC foods, such as tomato sauce, because much of the EC results from sodium compounds.

Sugar dissolved in deionized water has an EC of zero, as does rubbing alcohol (isopropyl alcohol), because sugar and alcohol do not ionize. Household cleaners often have a high EC. The EC of some

Table 1. Electrical Conductivity of Common Substances

Substance	EC at 25°C, dS/m
De-ionized, or distilled, water	0.0
Perrier bottled water	0.7
Coca-Cola	0.7
1% milk	5.2
Tomato sauce	17.9
Sugar water (17.5 g/liter)	0.0
Rubbing alcohol	0.0
Formula 409 cleaner	10.0
Clorox bleach (1:10 dilution)	13.2
Seawater (1:5 dilution)	10.3
Miracle-Gro fertilizer (0.9 g/liter)	0.9

substances is so high that they must be diluted prior to EC measurement. For example, a 1:5 dilution of seawater is obtained by taking one volume of seawater and adding four volumes of deionized water. To estimate the EC of undiluted seawater, multiply the EC of the dilute solution, 10.3, by 5 to obtain 51.5 dS/m.

Salty Soil

Elementary students can also bring in soil samples for EC measurement. A good time of year for this activity is winter, when salt is applied to sidewalks to melt ice. Students can take samples next to sidewalks that were treated with ice-melting salt and from areas more distant from the treated sidewalks. The easiest way to prepare the soil for EC measurement is to add two volumes of distilled or deionized water to one volume of soil. After thorough mixing, the soil is allowed to settle, and the EC of the solution above the soil is measured. Cheap soil-salinity meters are widely sold, but they are inaccurate (Hershey 1992).

Salty Sauce

Have junior-high-level students measure the EC of a salty food like spaghetti sauce, and then ask them to calculate how much salt is in the sauce. For example, an 800 ml jar of spaghetti sauce had an EC of 15.1 dS/m. The label indicated that the jar had 670 mg sodium per serving, and there were 7.5 servings per jar. The total amount of sodium was 670 × 7.5 = 5025 mg, or 5.025 g.

Provide the students with table salt, an empty spaghetti jar, and distilled water and ask them to prepare a solution with the same sodium concentration as the sauce. Because NaCl is not pure sodium, more than 5 g must be added. The NaCl contains 23/58.5 × 100 (39%) Na, so 5/0.39 (12.8 g) NaCl must be added to the jar of distilled water to obtain the same sodium concentration as in the sauce. (The atomic weight of sodium is 23, and the molecular weight of NaCl is 58.5.) If a balance is not available, have students measure salt with a 0.25 teaspoon measure, remembering that a level 0.25 teaspoon is about 1.5 g NaCl. Thus, 12.8 g NaCl = 12.8/1.5 = 8.5 level 0.25 teaspoons.

After students have prepared the salt solution, have them measure the EC. They will find that the reading is off the scale. Can the EC still be determined? Yes, if the solution is diluted 1:2 by adding one volume of distilled water to one volume of salt solution. The EC reading of the diluted solution factor of 2 gives an estimated EC of 23.4 dS/m. Why is this so much higher than that of the spaghetti sauce? A possible hypothesis is that the thick sauce conducts electricity less efficiently than the salt solution. But how could this theory be tested?

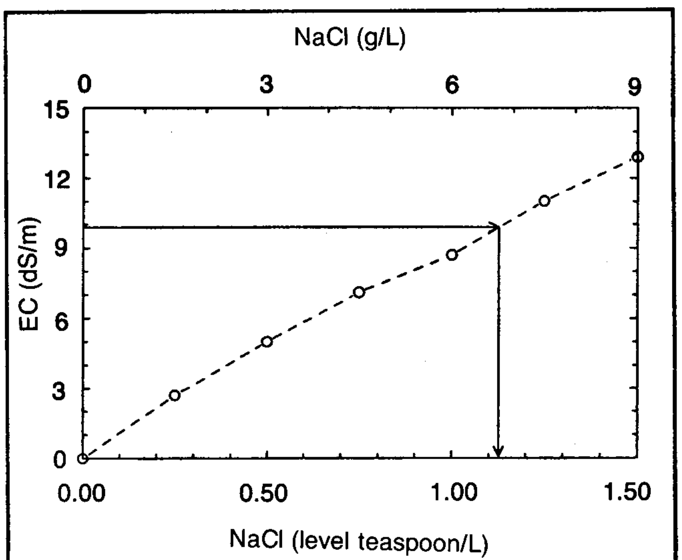

Figure 3. Standard curve of the relationship between NaCl concentration and EC measured with a pocket EC meter.

Standard Curve Preparation and Use

A standard curve is a graph of the concentration of a substance against the reading on an instrument that measures the concentration of that substance. A graph of salt concentration and EC can be used as a standard curve to allow quick estimation of salt concentration by measuring EC. Have junior-high-level students prepare a standard curve by adding table salt to distilled water, using a balance or 0.25 teaspoon to measure the amount of salt (figure 3). After preparing the standard curve, have students read the EC of another NaCl solution and estimate its EC using the standard curve. For example, if the EC is 10 dS/m, draw a horizontal line at 10 dS/m until the NaCl curve is intercepted (see figure 3). Then drop a vertical line to the horizontal axis to determine the salt concentration. In this example, the NaCl concentration is about 1.13 teaspoon/L, or 6.8 g/L.

Other Ideas

An EC meter can also be used in many other activities. For example, plants grown in hydroponics will deplete the hydroponic solution of ions, thus purifying the water (Hershey 1990). Students can use an EC meter to monitor the nutrient solution and measure the rate of ion uptake by the plant. Freezing injury to plant tissues is also often quantified by measuring the EC. Place a group of leaves or twigs in a freezer and keep another group at room temperature. Thaw the frozen tissues, and then place samples of thawed and unfrozen plant tissue in an identical volume of distilled water and measure the EC. The EC of the frozen tissues should be higher than that of the unfrozen tissues because ions leak from freeze-damaged tissues.

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