

5.2 Types of Aqueous Solutions and Solubility

When an ionic compound dissolves in water, the positive and negative ions originally present in the crystal lattice persist in solution. Their ability to move nearly independently through the solution permits them to carry positive or negative electrical charges from one place to another. Hence the solution conducts an electrical current.

Electrolytes

Substances whose solutions conduct electricity are called electrolytes. All soluble ionic compounds are **strong electrolytes**. They conduct very well because they provide a plentiful supply of ions in solution. An example of an ionically-bonded compound that is a strong electrolyte is NaCl:



Some ionically-bonded substances behave as **weak electrolytes**—their solutions allow only a small current flow, but it is greater than that of the pure solvent. An example is mercury(II) chloride (seen in the Figure above). For a 100-*M* HgCl₂ solution the meter reading shows only about 0.2 percent as much current as for 0.10 *M* NaCl. When the solid dissolves only a few ions dissociate according to the equation



(The double arrows indicate that the ionization proceeds only to a limited extent and an equilibrium state is attained.)

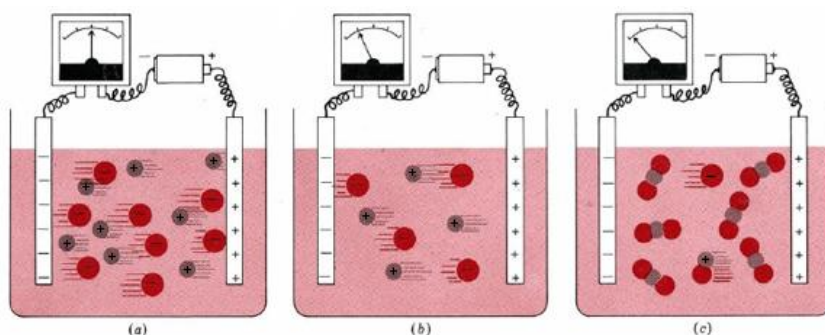


Figure 1: The conductivity of electrolyte solutions: (a) 0.1 *M* NaCl (b) 0.05 *M* NaCl (c) 0.1 *M* HgCl₂. An electrolyte solution conducts electricity because of the movement of ions in the solution (see above). The larger the concentration of ions, the better the solutions conducts. Weak electrolytes, such as HgCl₂, conduct badly because they produce few ions when dissolved (low concentration of ions).

The effect of the concentration of ions on the electrical current flowing through a solution is illustrated in Fig. 1. Part *a* of the figure shows what happens when a battery is connected through an electrical meter to two inert metal strips (**electrodes**) dipping in ethanol. Each cubic decimeter of such a solution contains 0.10 mol NaCl (that is, 0.10 mol Na⁺ and 0.10 mol Cl[−]). An electrical current is carried through the solution both by the Na⁺ ions moving toward the negative electrode and by the Cl[−] ions which are attracted toward the positive electrode. The dial on the meter indicates the quantity of current.

Figure 1*b* shows that if we replace the 0.10-*M* NaCl solution with a 0.05-*M* NaCl solution, the meter reading falls to about one-half its former value. Halving the concentration of NaCl halves the number of ions between the electrodes, and half as many ions can only carry half as much electrical charge. Therefore the current is half as great. Because it responds in such a direct way to the concentration of ions, conductivity of electrical current is a useful tool in the study of solutions.

Figure 1*c* shows that if we replace the 0.10-*M* NaCl solution with a 0.10-*M* HgCl₂ solution, the meter reading falls to a small fraction of its former value. Very few ions are formed in solution by the HgCl₂. Since only 0.2 percent of the HgCl₂ forms ions, the 0.10 *M* solution can conduct only about 0.2 percent as much current as 0.10 *M* NaCl.

Conductivity measurements reveal that most covalent compounds, if they dissolve in water at all, retain their original molecular structures. Neutral molecules cannot carry electrical charges through the solution, and so no current flows. A substance whose

aqueous solution conducts no better than water itself is called a **nonelectrolyte**. Some examples are oxygen, O_2 , ethanol, C_2H_5OH , and sugar, $C_{12}H_{22}O_{11}$. The process of the molecules dissolving intact is shown by an equation such as:



However, some polar covalent compounds are also strong electrolytes because they react with water to form ions. Common examples are HCl, HBr, HI and H_2SO_4 , all of which react with H_2O to form large concentrations of ions. For HCl, the reaction is:



There are also some covalently-bonded compounds that behave as weak electrolytes. Ammonia is a common example. Only a small fraction of ammonia molecules react with water to form ions:



Conductivity measurements can tell us more than whether a substance is a strong, a weak, or a nonelectrolyte. Consider, for instance, the data in Table 1 which shows the electrical current conducted through various aqueous solutions under identical conditions. At the rather low concentration of 0.001 M, the strong electrolyte solutions conduct between 2500 and 10 000 times as much current as pure H_2O and about 10 times as much as the weak electrolytes $HC_2H_3O_2$ (acetic acid) and NH_3 (ammonia).

Closer examination of the data for strong electrolytes reveals that some compounds which contain H or OH groups [such as HCl or $Ba(OH)_2$] conduct unusually well. If these compounds are excluded, we find that 1:1 electrolytes (compounds which consist of equal numbers of +1 ions and -1 ions) usually conduct about half as much current as 2:2 electrolytes (+2 and -2 ions), 1:2 electrolytes (+1 and -2 ions), or 2:1 electrolytes (+2 and -1 ions).

TABLE 1: Electrical Current Conducted Through Various 0.001 M Aqueous Solutions at 18°C.*

Substance	Current /mA	Substance	Current /mA
Pure Water		1:2 Electrolytes	
H_2O	3.69×10^{-4}	Na_2SO_4	2.134
Weak Electrolytes		Na_2CO_3	2.24
$HC_2H_3O_2$	0.41	K_2CO_3	2.660
NH_3	0.28	2:1 Electrolytes	
1:1 Electrolytes		$MgCl_2$	2.128
NaCl	1.065	$CaCl_2$	2.239
NaI	1.069	$SrCl_2$	2.290
KCl	1.273	$BaCl_2$	2.312
KI	1.282	$Ba(OH)_2$	4.14
$AgNO_3$	1.131	2:2 Electrolytes	
HCl	3.77	$MgSO_4$	2.00
HNO_3	3.75	$CaSO_4$	2.086
NaOH	2.08	$CuSO_4$	1.97
KOH	2.34	$ZnSO_4$	1.97

* All measurements refer to a cell in which the distance between the electrodes is 1.0 mm and the area of each electrode is 1.0 cm². A potential difference of 1.0 V is applied to produce the tabulated currents.

There is a simple reason for this behavior. Under similar conditions, most ions move through water at comparable speeds. This means that ions like Mg^{2+} or SO_4^{2-} , which are doubly charged, will carry twice as much current through the solution as will singly charged ions like Na^+ or Cl^- . Consequently, a 0.001 M solution of a 2:2 electrolyte like $MgSO_4$ will conduct about twice as well as a 0.001 M solution of a 1:1 electrolyte like NaCl.

A similar argument applies to solutions of 1:2 and 2:1 electrolytes. A solution like 0.001 M Na_2SO_4 conducts about twice as well as 0.001 M NaCl partly because there are twice as many Na^+ ions available to move when a battery is connected, but also because SO_4^{2-} ions carry twice as much charge as Cl^- ions when moving at the same speed. These differences in conductivity between different types of strong electrolytes can sometimes be very useful in deciding what ions are actually present in a given electrolyte solution as the following example makes clear.

A second, slightly more subtle, conclusion can be drawn from the data in Table 1. When an electrolyte dissolves, each type of ion makes an independent contribution to the current the solution conducts. This can be seen by comparing NaCl with KCl , and NaI with KI . In each case the compound containing K^+ conducts about 0.2 mA more than the one containing Na^+ . If we apply this observation to Na_2CO_3 and K_2CO_3 , each of which produces twice as many Na^+ or K^+ ions in solution, we find that the difference in current is also twice as great—about 0.4 mA.

Thus conductivity measurements confirm our statement that each ion exhibits its own characteristic properties in aqueous solutions, independent of the presence of other ions. One such characteristic property is the quantity of electrical current that a given concentration of a certain type of ion can carry.

Example 1: Ions

At 18°C a 0.001-M aqueous solution of potassium hydrogen carbonate, KHCO_3 , conducts a current of 1.10 mA in a cell of the same design as that used to obtain the data in Table 11.1. What ions are present in solution?

Solution

Referring to Table 6.2 which lists possible polyatomic ions, we can arrive at three possibilities for the ions from which KHCO_3 is made:

- K^+ and H^+ and C^{4+} and three O^{2-}
- K^+ and H^+ and CO_3^{2-}
- K^+ and HCO_3^-

Since the current conducted by the solution falls in the range of 1.0 to 1.3 mA characteristic of 1:1 electrolytes, possibility c is the only reasonable choice.

Contributors

- Ed Vitz (Kutztown University), [John W. Moore](#) (UW-Madison), [Justin Shorb](#) (Hope College), [Xavier Prat-Resina](#) (University of Minnesota Rochester), Tim Wendorff, and Adam Hahn.
- Modified by [Tom Neils](#) (Grand Rapids Community College)

5.2 Types of Aqueous Solutions and Solubility is shared under a [CC BY-NC-SA 4.0](#) license and was authored, remixed, and/or curated by LibreTexts.