



## Water Softeners

### Hard Water v. Soft Water Conductivity v. Resistance

#### What is "Hard Water"?

Perhaps you have on occasion noticed mineral deposits on your cooking dishes, or rings of insoluble soap scum in your bathtub. These are not signs of poor housekeeping, but are rather signs of *hard water* from the municipal water supply. Hard water is water that contains cations (a group of atoms carrying a positive electrical charge) with a charge of +2, especially  $\text{Ca}^{2+}$  and  $\text{Mg}^{2+}$ . These ions do not pose any health threat, but they can engage in reactions that leave insoluble mineral deposits. These deposits can make hard water unsuitable for many uses.

#### Hard Water

Mineral deposits are formed by ionic reactions resulting in the formation of an insoluble precipitate. A precipitate is an insoluble substance separated from a solution in a concrete state by the action of some reagent added to the solution, or of some force, such as heat or cold. The precipitate may fall to the bottom of the container.

For example, when hard water is heated,  $\text{Ca}^{2+}$  ions react with bicarbonate ( $\text{HCO}_3^-$ ) ions to form insoluble calcium carbonate ( $\text{CaCO}_3$ ), as shown below.



This precipitate, known as *scale* (insoluble calcium carbonate ( $\text{CaCO}_3$ )), coats the vessels in which the water is heated and producing the mineral deposits on your cooking dishes and around sink fixtures. In small quantities, these deposits are not harmful, but they may be frustrating to try to clean. As these deposits build up, however, they reduce the efficiency of heat transfer.

Precipitation inducing inhibitors are film forming compounds that have a general action over the metal surface, blocking both anodic and cathodic sites indirectly. Precipitation inhibitors are compounds that cause the formation of precipitates on the surface of the metal, thereby providing a protective film. Hard water that is high in calcium and magnesium is less corrosive than soft water because of the tendency of the salts in the hard water to precipitate on the surface of the metal and form a protective film.

<http://www.corrosionsource.com/technicallibrary/corrdctors/Modules/Inhibitors/precipitation.htm>

#### Soft Water

Pure water consists of hydrogen and oxygen,  $\text{H}_2\text{O}$ , and is a colorless, odorless, tasteless, transparent liquid, which is very slightly compressible. It is the most important natural solvent, and is frequently impregnated with foreign matter which is mostly removed by distillation; hence, rain water is nearly pure. Soft water is water without any cations (magnesium or calcium). Distilled water, by definition, is soft water.

Household water softeners typically use a process known as ion exchange. Ion-exchange devices consist of a bed of plastic (polymer) beads covalently bound to anion groups (a group of atoms carrying a negative electrical charge). The negative charge of these anions is balanced by  $\text{Na}^+$  (sodium) cations



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attached to them. When water containing  $\text{Ca}^{2+}$  and  $\text{Mg}^{2+}$  (hard water containing calcium and magnesium) is passed through the ion exchanger, the  $\text{Ca}^{2+}$  and  $\text{Mg}^{2+}$  ions are more attracted to the anion groups than the  $\text{Na}^+$  ions. Hence, they replace the  $\text{Na}^+$  ions on the beads, and so the  $\text{Na}^+$  (sodium ions) which do not form scale, go into the water in their place.

<http://www.chemistry.wustl.edu/~edudev/LabTutorials/Water/FreshWater/hardness.html>

### Conductivity and Resistance of Water

You may wonder what it has to do with the measurement of the conductivity of water--the real question from the beginning. So, we are now going into the main subject. A metal, such as in an electric wire, contains a great number of free electrons. These electrons pass electric current from one to the next, just like a line of people forming a bucket brigade. Such a metal is called a conductor. The next subject involves what is called an ion conductor, basically ions in an electrolyte solution, which also affect the conducting of electricity.

When a substance like  $\text{Ca}^{2+}$  and  $\text{Mg}^{2+}$  (hard water containing calcium and magnesium) is dissolved in liquid and the liquid can conduct electricity. Such a liquid is called an electrolyte solution, and the dissolved substance is called an electrolyte. And each minute particle that carries electricity is called an ion (a Greek word meaning wanderer).

Common table salt ( $\text{NaCl}$ ) is an electrolyte, and when this is dissolved in water to form salt water, it becomes sodium ions ( $\text{Na}^+$ ) and chlorine ions ( $\text{Cl}^-$ ), each of which is a particle that conducts electricity.

Now, let's go back to conductivity. Conductivity is an index of how easy it is for electricity to flow. In water, it is the ions (the small minute particles of substance) that pass electricity from one to the next. This means that the more  $\text{Na}^+$  and  $\text{Cl}^-$  contained in water the more electricity is carried, and the higher the conductivity. ([http://global.horiba.com/story\\_e/conductivity/conductivity\\_03.htm](http://global.horiba.com/story_e/conductivity/conductivity_03.htm))

Resistance becomes an index of difficulty of flow of electric current. And the reciprocal of resistance is conductivity. So, conductivity becomes an index of ease of flow of electric current. ([http://global.horiba.com/story\\_e/conductivity/conductivity\\_02.htm](http://global.horiba.com/story_e/conductivity/conductivity_02.htm))

Many people become more active in summer than in winter. The ions in an electrolyte solution likewise become more active when the temperature rises – making it easier for electricity to flow. Of course, you know that heat is the movement of molecules and ions that make up a substance.

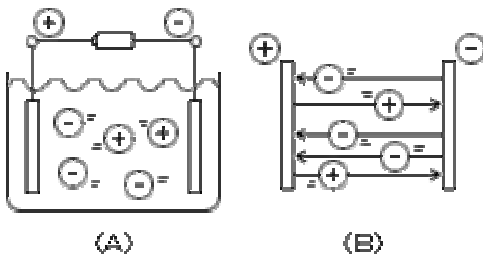
In other words, as the temperature of a conductive solution rises, its conductivity increases. Also, just as each human has a different personality, ions have different characteristics. Even with the same temperature variation, ions become active differently, depending on the kinds of ions and the density of the solution. Water differs from place to place in the US; each water source having its own characteristics or personality.

### The Experiment – Measure the resistance of water



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So to review, an electrolyte solution contains positive ions, each of which has a positive electrical charge, and negative ions, each of which has a negative electrical charge. As illustrated in Fig. (A), we will now place a pair of metal plates at opposite sides in an electrolyte solution, and connect a battery. With such a setup, the positive ions move toward the plate connected to the negative terminal of the battery, and the negative ions move toward the plate connected to the positive terminal of the battery, and thus electric current flows through the solution. You will see one end of the metal copper wire become very active in solution (anode) while the other side of the metal wire is not active (cathode).



When a voltage is applied, the ions move straight toward the respective oppositely charged metal plates, as illustrated in Fig. (B). ([http://global.horiba.com/story\\_e/conductivity/conductivity\\_04.htm](http://global.horiba.com/story_e/conductivity/conductivity_04.htm))

In this experiment, you will make "hard" water from distilled water, which contains no minerals, and is therefore "soft." The minerals that make water hard usually contain calcium and magnesium. In this experiment, you made water hard by adding Epsom salt, which is magnesium sulfate.

Measure one cup of distilled water and place it in a plastic container labeled SOFT water.

Measure one cup of distilled water and place it in a plastic container labeled HARD water. Add 2-3 teaspoons full of Epsom salt to the water and stir until dissolved.

Measure one cup of tap water and place it in a plastic container labeled TAP water.

Now set up a battery with copper wires in each of the containers. Note the reaction of the ends of the copper in each container. Explain why?

Measure the Ohms resistance of the water by using a multi-meter set up to measure resistance. Which solution(s) have a resistance? Why?

What can you conclude about soft water and water softeners from this experiment?

1. Soft water that does not contain enough mineral content to be conductive will not allow the proper electrical reaction between the anode and the steel tank (cathode). If there is little or no electrical reaction between the anode and steel tank, then the tank will not be protected. If the tank is not protected, it will rust sooner than designed.
2. The softer the water, the less ability for the proper electrical reaction to occur. In 'dead soft water' (like distilled water), the anode is completely ineffective.
3. If the water softener is not maintained in an optimum condition, you really do not know what chemical reactions are taking place as the softened water is introduced into the water heater.
4. A small formation of scale on the steel surfaces inside a water heater is a good thing. It helps to protect the tank from the aggressive nature of water. Too much scale is a bad thing and will settle



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to the bottom of the tank or accumulate on heating elements. More serious is the situation in which water heaters become totally encrusted with scale due to excessively hard water. The cost in heat-transfer efficiency can have a dramatic effect on your power bill! Furthermore, scale can accumulate on the inside of appliances, such as dishwashers, and pipes. As scale builds up, water flow is impeded, and hence appliance parts and pipes must be replaced.

5. Hotter water (like in a water heater) causes these reactions to be more aggressive.