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Study of Electrical Conductivity of Different Water Liquids and Electrolytes

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Abstract: In this study electrical conductivities of pure, distilled, municipal, industrial and river water liquids along with those of different electrolyte solutions are computed at room temperature (25 °C) and compared with the experimental results. For experiment, using a measuring module both R and C value of the water samples are measured by using two different cylindrical cells. The obtained RC product for the long and short cell probes are compared for different water samples. Obtained results give the relaxation time, which is the measure of the conduction relaxation and for a good conducting medium such a time is very short. The relaxation time for the salt solution is about 0.07044 ms (0.07038 ms for short probe) for boiled water 0.355 ms (0.350 ms), tap water 0.374 ms (0.364 ms), mineral water 0.524 ms (0.515 ms), and finally for the distilled water is about 8.059 ms (6.943 ms). The conductivity of samples are measured by the EC instrument and then by using the RC values the imaginary part of the permittivity values for different liquid samples are determined. The imaginary part of the permittivity for the distilled water is the minimum value of about 23.67×10^{-7} (F/m) while for the salt water solutions is the highest value of 220.99×10^{-7} (F/m).

Key words: Water, electrolyte, electrical conductivity, cell

INTRODUCTION

Water is one of the most important matters in the nature and widely used for different purposes in a variety of applications. Water substance can be in form of vapor, liquid, or solid phase. Pure water is a clear, colorless, and odorless liquid that is chemically made up one oxygen and two hydrogen atoms. This powerful substance is a good medium for many reactions, which is used as a universal solvent. Physical and chemical properties of water results from strong attraction that hydrogen atoms have for each other in water molecules. For many applications water solution is grouped into ultra pure, pure, and regular water depending on the percentage of impurities (Huang, *et al* 1998; Tsamis and Avaritsiotis, 2005; Light, *et al* 2005; Weast, 1981).

Although pure water is a poor conductor of electricity, but natural impurities found in water can transform it into a relatively good conductor. A variety of methods have been developed to measure and test the refined water products in order to specify the purity of the produced samples. Salts and other contaminates in water can dissociate into components called ions. Ions in water are considered as impurities especially when referring to pure water, while in other aqueous solutions such as sodium hydroxide, the ions define the actual chemical deposition. In general, the electrical conductivity of the solution has been one of the important physical quantities in this respect and many probes and devices such as conductive sensors have been devised (Golnabi and Azimi, 2008; Strizzolo and Cinverti, 1993; Reverter, 2006; Niu, *et al* 2009; Stott, *et al* 1985). Such probes are used to measure conductivity of the solutions at the given concentration and temperature. Development and applications of different capacitance sensors and measuring systems are given in literature(Wu, *et al* 2009; Abu-Al-Aish and Rehman, 2009; Chiang, *et al* 2007; and Cheng, *et al* 2006).

Electrical conductivity of solutions has been studied for several reasons such as studying the process of salvation, association and transparent properties of ions in different solvent media. Such processes depend on the charge, radius, and hydrate numbers of ions and the nature of solvent. Electrolytic conductivity is a measure of ability of a solution to conduct an electric current and is defied by the specific conductance or term conductibility. Conductivity is the inverse of electrical resistivity, which defined as the measure of the ability of a solution to resist an electric current flow.

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Electric Conduction:

A point charge at rest produces the electrostatic field and electric potential around it and moving charges constitute a current, and thereby charge is transported is called conduction. The electric current is defined as the rate which, charge is transported past a defined point in a conducting system. In a metal, current is carried by electrons, while the heavy positive ions are fixed at regular positions in the metallic crystal structure. It must be mentioned that only the valence (outmost) atomic electrons are free to move and participate in the conduction process; while the other electrons are tightly bound to their ions. In general, an electric current arises in response to an applied electric filed or electric potential difference.

If an electric field is imposed on a conductor, it will cause positive charge carries to move in the direction of the field and negative carries in the direction opposite to the filed; hence all currents produced in this process have the same direction as the electric field. The charge carriers as falling into groups, each of which has a common motion called the drift motion (velocity) of the group. Such currents are known as conduction currents; however currents arising from mass transport (hydrodynamic motion) are called convection currents that may occur in liquids and gases. Convection currents are important to the subject of atmospheric electricity in the thunderstorms process. In an electrolyte solution, when an external electric field is applied to the object the current is carried by both positive and negative ions, although, because some ions move faster than others, conduction by one type of ions usually predominates. It is noted that positive and negative ions traveling in opposite directions in such a medium contribute to the unified current in the same direction.

A steady-state conduction problem can be solved in the same way as electrostatic problem. Consider a homogeneous, isotropic medium characterized by conductivity g and permittivity ε. Steady-state conduction problem may be solved in the same way as electrostatic Laplace's equation. Consider two separate metallic conductors in a homogeneous, isotropic, and ohmic medium of moderate conductivity, g, like a salt solution. If the metallic conductors are maintained at the potentials U_1 and U_2, then the current flow, I, between two electrodes is given by

$$I = \frac{U_1 - U_2}{R} \tag{1}$$

where R is the resistance of the medium. Such a current may be considered as the steady-state current in a medium without a source of electromotive force.

Now consider the produced electric current in the inhomogeneous medium. Let us consider a conduction object composed of ohmic material, but which is not necessarily as before homogenous, so that the conductivity g is independent of the local electric field but vary from point to point in the medium. For this case instead of a constant conductivity factor, g, we must consider g(x,y,z). Suppose two points on the boundary of the conducting object are maintained at the potentials U_1 and U_2, respectively. The current lines for such a medium from Ohm law follow those of the local electric field (J=gE), and the equipotential surfaces intersects the current lines at right angles are not necessarily parallel to each other for this medium. In this case actually we can consider a large resistance network constructed from many elemental resistors R_i in the shape of short wire segments. According to the resistance formula for a resistor we have

$$R_i = \frac{\ell_i}{g_i A_i} \tag{2}$$

where $g_i(x,y,z)$ is the local conductivity, A_i is the cross-sectional area of the segment, and ℓ_i is the distance between the equipotential surfaces. In the limiting case where the number of the equipotential surfaces between U_1 and U_2 becomes very large and the number of elemental resistors becomes correspondingly large, the resistors R_i fill the entire space occupied by the conducting object. Thus such a network has an equivalent resistance R that can be considered in Eq. (1).

The generated electric current may be written in terms of the current density, J, in the medium such as

$$I = \oiint_S J.nda \tag{3}$$

where S is any closed surface, which completely surrounds one of the conductors and, *n,* is the surface unit vector perpendicular to surface element. But we have $J = gE$ and by combining Eqs. (1) and (3) one obtains

$$\frac{U_1 - U_2}{R} = g\oint_S E.nda \tag{4}$$

On the other hand, if the identical electric field were produced by electrostatic charge, Q, on the two metallic conductors, then by Gauss' law (assuming very long conductors) we can write

$$\oint_S E.nda = \frac{Q}{\varepsilon} \tag{5}$$

where ε is the permittivity of the medium, and in this condition two conductors form a capacitor with the charge value of

$$Q = C\left(U_1 - U_2\right) \tag{6}$$

and by insertion of Eq.(6) and (5) into (4) we can write

$$RC = \frac{\varepsilon}{g} \tag{7}$$

which, is a relation between the equivalent resistance of the medium and the effective capacitance of the electrostatic problem.

Let us now consider the approach to electrostatic equilibrium in a conductive object. The question is how we describe the effect of the extra charge on a conductor. It is shown that the excess charge on a conductor resides on its surface. This is off course the equilibrium situation and for a good metallic conductor the attainment of the equilibrium is extremely rapid. The poorer the conductor, the slower is the approach to electrostatic equilibrium. In fact if the conductivity of the material is extremely low, it may takes years or even longer to reach the electrostatic equilibrium. As before consider a homogeneous, isotropic medium characterized by conductivity g and permittivity ε, which, has a volume density of free charge ρ(x,y,z). If this conducting system is suddenly isolated from source of emf and time-dependent electric field, it will tend toward the equilibrium situation where there is no excess charge in the interior of the system. According to the equation of the charge continuity:

$$\frac{\partial \rho}{\partial t} + divJ = 0 \tag{8}$$

which with the aid of Gauss' law can be written as and the relation to the source of the field according to Maxwell equation and we have

$$\frac{\partial \rho}{\partial t} + \frac{g}{\varepsilon}\rho = 0 \tag{9}$$

and the solution of this partial differential equation is

$$\rho(x, y, z) = \rho_0(x, y, z)\exp(-gt/\varepsilon) \tag{10}$$

From Eq.(10) it is observed that the equilibrium state is approached exponentially. It is also evident that the quantity ε/g has the time dimension and it is called the time constant or relaxation time, t_c , of the medium, so one can write

$$t_c = \frac{\varepsilon}{g} = \varepsilon\eta \tag{11}$$

where η is defined as resistivity of the medium (ohm-m). Time constant is measure of how fast the conducting medium approaches the electrostatic equilibrium; precisely, it is the time required for the charge in a specific region to decrease to 1/e of its original value.

A material will reach its equilibrium charge distribution in a specific application when its time constant is much shorter than the characteristic time required to make the pertinent measurement. For some applications a time constant of less than 0.1 s is sufficient to ensure conductorlike behavior; since most permittivities fall into the range ε_0 to 10 ε_0, this require a material with resistivity η less than 10^9 or 10^{10} ohm-m. For high-frequency applications a shorter time constant, and a correspondingly smaller resistivity, is required for the true conductorlike behavior. In fact

$$t_c << \frac{1}{f} \tag{12}$$

must be satisfied in which f is the highest frequency involved in the experiment.

In general the complex permittivity of a medium can be written as

$$\varepsilon = \varepsilon' + j\varepsilon'' = \varepsilon' + j\frac{g}{\omega} \tag{13}$$

where έ is the real, ε” is the imaginary part of the permittivity and $\omega = 2\pi f$. The condition for a good conductor medium is that the imaginary part to be much larger than the real part, i.e.

$$\left(\frac{g}{\varepsilon'\omega}\right)^2 >> 1 \tag{14}$$

where g is the conductivity. For a good dielectric medium the given ratio must be much less than unity. For the metallic conductive materials the conductivity is high (for copper 5.88 $\times 10^7$mho/m or S/m) while for the good dielectric medium the permittivity is high (for distilled water is about $80\varepsilon_0$)

***Electrical Conductivity of Liquids*:**

Generally water molecules are in continuous motion, even at low temperatures and when two water molecules collide, a hydrogen ion is transferred from one molecule to the other. The other molecule that losses the hydrogen ion becomes negatively charged hydroxide ion. The molecule that gains the hydrogen ion becomes a positively charged hydrogen ion and this process is commonly called the self-ionization of water. In fact at room temperature (25 °C), each concentration of hydrogen ions and hydroxide ions is only of the order of 1×10^{-7} M, and as a result this dissociation allows a minute electrical current to flow. The current flow is in the range of conductivity of 0.05 μS/cm at room temperature. It is important to note that the amount of $(H)^+$ and $(OH)^-$ ions are approximately equal and this solution is described as a neutral solution.

In other aqueous solutions, the relative concentrations of these ions are unequal and one ion is increased by one order of magnitude while the other one shows some decrease, but the relationship is constant and the ion product is always constant given by K_w, which is called the ion-product constant for water. Water is a polar solvent with an uneven distribution of electron, and the application of electric field causes one portion of the molecule to be somewhat positive and another part negative (polarization effect). In an external DC electric field, the dissolved electrolyte substances are free to move and positive charged particles move towards negative electrode while negative charged particles migrate toward the positive electrode. The migration of the charged particles causes the electric current flow in liquid. Such DC polarization can be eliminated by using AC voltage at 60 Hz or higher frequencies and in practice by increasing the cross sectional area of the electrodes.

The mechanism of electrical conduction through a liquid is different in comparison with a solid. In solid, when a potential is applied to a solid conductor, the flow of current is instantaneous, and is virtually proportional to the applied potential. In addition, different types of materials conduct electrical charges with different efficiencies. In metals, there are free electrons, which are available for conduction even at a very low temperature. One major difference of a metal with semiconductor and isolator materials is that metal resistance increases as the metal heated because of the decrease in electron mobility. Conversely, the resistance of semiconductors and insulators decreases with increasing temperature because the number of charge carries increases. Therefore, in semiconductor and in particular in insulators, more activation energy is needed to excite electrons to be available to conduct a charge.

The conductivity of a solution relates to the total dissolved solid (TDS) and amount of the suspended solids (SS) or insolvable solids in a water sample. Total dissolved solid includes solid particulates such as ions, inorganic substances, salts, and metals. Total solid (TS) is defined as the sum of TDS and SS. In laboratory analysis measurement of these parameters are made by filtering and weighing to determine SS, then drying and weighing to determine TDS. In analysis of water the conductivity measurements are classified for the Ultra-pure, high-purity and pure water samples, which show accordingly an increase in the conductivity value (0.053 μS/cm to 10 μS/cm).

The electrical conductivity of a conductor is given by the relation

$$g = nq\mu \tag{15}$$

where n is the density of charge carrier, q is the species charge , and μ is the charge particle mobility defined by the ratio of the applied electric field to the charge carrier velocity. The electrical conductivity of a semiconductor crystal is given by

$$g = \left(ne\mu_e + pe\mu_h\right) \tag{16}$$

where n and p are the concentration of electrons and holes, respectively. μ as defined is the mobility for the electron and hole, accordingly.

For pure water ionization the possible colliding reaction is

$$H_2O + H_2O \longrightarrow H_3O^+ + OH^- \tag{17}$$

and the K factor is defined by the ratio of species concentrations

$$K = \frac{[H_3O^+][OH^-]}{[H_2O][H_2O]} \tag{18}$$

where one can write

$$K[H_2O]^2 = [H_3O^+][OH^-] \tag{19}$$

and the term in the left hand side of Eq.(19) is always constant defined by K_w.

$$K_w = [H_3O^-][OH^-] \tag{20}$$

which is in most practical cases a constant. The conductance of electricity is a usual way to measure the mobility of ions and conductivity meters are used for this purpose. For liquids conductivity, g, is measured in unit of (S/m, mho/m) and the molar conductivity is a common expression for solutions, which is the conductivity per unit of concentration (Sm^2/mol). Conductivity meters measure and display conductivity g or resistivity 1/g of a sample solution at a given temperature. By using a standard solution (KCl) the constant K (S/cm) for a given cell probe is obtained.

By using the equality of the electric force and the friction force on ions for finding the velocity of ions for the electrolyte a general formula for the conductivity is given by

$$g = \frac{e^2 N_A}{6\pi\nu} \sum_i \frac{(Z_i C_i)}{r_i} \tag{21}$$

where C_i is the fractional concentration. Here e is the electric charge, r is the ionic radius, N_a is the Avogadro number, Z number of involved ions and ν is the ion viscosity. The electrical conductivity of water electrolyte in concentration equilibrium condition can be obtained by the multiplication of the K_w and the possibility factor for the ion generation in the ion migration process

$$g = K_w \exp(-\frac{\Delta G}{RT}) \tag{22}$$

which can be written as

$$g = \frac{e^2 N_A}{6\pi\nu} \sum_i \frac{Z_i}{r_i} \exp(-\frac{\Delta \mathrm{H}}{2RT}) \exp(\frac{\Delta S}{2R}) \tag{23}$$

where the equality of

$$\Delta G = \Delta \mathrm{H} - T\Delta s \tag{24}$$

is plugged into Eq.(22) for G, which defines the Gibbs free energy (kJ/mol). Here H is the enthalpy, s entropy, T temperature, and R the universal gas constant. By using the hydrodynamic radius of ions in (23) the conductivity becomes

$$g = \frac{e^2 N_A}{6\pi\nu} (1/r_{H30^+} + 1/r_{OH^-}) \exp(-\frac{\Delta \mathrm{H}}{2RT}) \exp(\frac{\Delta s}{2R}) \tag{25}$$

Experimental Arrangement:

Our experimental system as shown in Fig.1 includes a sensing probe and a measuring module. It uses a cylindrical capacitive sensor probe and either a LCR (Yuke-816, Good Will Instrument, Gw Instek) measuring module, or a digital multimeter (DMM) module (SANWA, PC 5000), that can be interfaced to a PC is used for measurements. The second measuring module is used in part of another investigation to study the dynamic behavior as stated in the previous report (Golnabi, 2008). For cell probe a cylindrical geometry as shown in Fig.1 is chosen and aluminum materials are used as the capacitor tube electrodes. The diameter of the inner electrode is about 18 mm and the inner diameter of the outer electrode is about 24 mm and has a thickness wall diameter of about 6 mm.

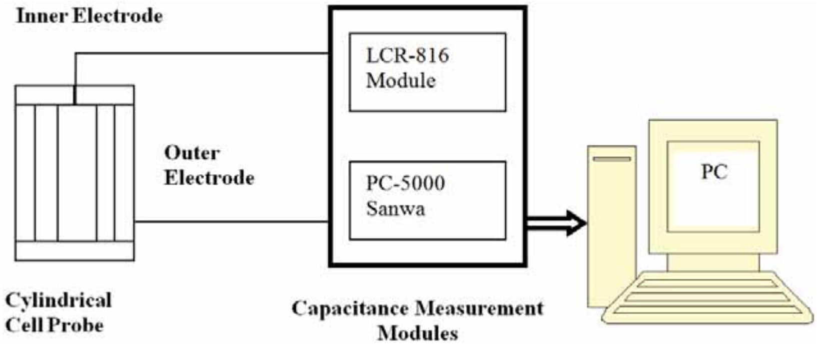

Fig. 1: Experimental arrangement used in this study.

Two cell probes are constructed with the similar structure with the effective length of 5 and 10 cm, which are referred to as short and long probes, respectively. The cylindrical gap volume measured when filled with water for the short sensor (5cm-length) is 10cc and for the long one (10 cm-length) is 20 cc. The radial gap between the two tube electrodes for filling medium is about 3 mm, and the overall diameter of the probe is about 44 mm. Two measurement leads as indicated in Fig.1; are connected to the inner electrode and outer electrode, respectively.

Our measuring instrument includes LCR-816 2kHz high precision LCR meter and a LCR-06A measuring probe. It uses the structure of four wires measurement, which allows accurate and stable measurements and avoids mutual inductance and interference from measurement signals, noise and other factors inherent with other types of connections. Four combinations of two parameters can be measured and displayed that could be parameters L (Inductance) and Q (quality factor), C (capacitance) and D (dissipation factor), C and R (resistance) or R and Q. Usually determination of C and R pairs is the goal in our experimental measurements. In this configuration meter displays the C, R and measurements can be performed in either series or parallel equivalent circuit. The accuracy for C and R measurements is about 0.05% (basic) + another error term that is defined from a given formula.

The distilled water used in this experiment was produced by an apparatus operating based on the boiling technique. For the water salt preparation regular grade salt (NaCl) was used for the preparation of a sample with the concentration of about 800 mg/L to 1600 mg/L. For the salt water original solutions with higher concentration was prepared first and then diluted according to the experiment requirement. These solutions were made carefully to ensure that the concentration of the salt was constant throughout a series of measurements.

RESULTS AND DISCUSSIONS

Based on the developed theoretical formulation different programs written in visual basics are executed in macro option of the Excel program. Four different water samples are considered for the first study and the computed results for the electrical conductance are reported. Fig. 2 shows he computed results for different water liquids including the pure, distilled, municipal, industrial, rivers and well waters. Samples indicated as PW (Pure Water), DW (Distilled Water,5 ppm), MUW (Municipal water,100 ppm), IW (Industrial Water,250 ppm) and finally RW (River Water, 500 ppm). As can be seen the electrical conductance ranging from a low value of 0.053 μS/cm (pure water) to 750.0 μS/cm for the high impurity level river water resource. The value of the electrical conductance is given for the room temperature of 25°C for all samples.

In the next study variations of electrical conductivity in respect to the impurity concentration for the distilled water are investigated. Impurity concentration is varied from 0.03 ppm to 10 ppm for the distilled water. Samples indicated as DW1=0.03 ppm, DW2=1 ppm, DW3=5 ppm and DW4=10 ppm are considered for this computation. The calculated electrical conductivity ranging from a low value of 0.0639 μS/cm (DW1) to 19.99 μS/cm for the high impurity 10 ppm water resources(DW4). The values of the electrical conductivities are given for the room temperature of 25°C for all samples. As can be seen, electrical conductivity shows increase by increasing the amount of the foreign impurity at the given temperature.

In another study variation of electrical conductivity of municipal water as a function of impurity is shown. Here typical concentration is increased from 100 ppm to 500 ppm for the municipal water samples. The electrical conductivity shows an increase by increasing the amount of the foreign impurity. For example for the same room temperature of (25 °C), the electrical conductivity for 100 ppm is about 200 μS/cm while it is increased to about 1000 μS/cm for the impurity concentration of 500 ppm.

In the next study electrical conductivity for seventeen different electrolyte solutions are computed and the results are discussed here. Results for the electrical conductance at room temperature (25 °C, typical concentration of 0.025 Mol/Lit) are presented in Fig. 3. As can be seen the electrical conductivity ranging from a low value of 2807.57 μS/cm (for NaCl) to the highest value of 35227.12 μS/cm for the BaOH solution. All the values of the electrical conductivity are given for the room temperature and a molar concentration of 0.025 Mol/Lit. The variation of electrical conductivity of H_2SO_4 electrolyte as a function of molar concentration (Mol./Lit) is investigated. In this study concentration is increased from 0.025 Mol/Lit to 1 Mol/Lit for the H_2SO_4 electrolyte sample and the electrical conductivity shows an increase by increasing the amount of the electrolyte concentration. For example for the same room temperature of (25 °C), the electrical conductivity for 0.025 Mol/Lit is about 20464.24 μS/cm, for 0.5 Mol/Lit is about 338747.68 μS/cm while it is increased to about 602230.85 μS/cm for the electrolyte concentration of 1 Mol/Lit.

In Fig.4 variation of electrical conductivity of NaCl electrolyte as a function of molar concentration (Mol./Lit) is presented. In this study concentration is increased from 0.025 Mol/Lit to 1 Mol/Lit for NaCl electrolyte. Similar to the previous case electrolyte concentration is varied and as can be seen in Fig.4, electrical conductivity shows a notable increase by increasing the concentration of the electrolyte. For example, at the same room temperature of (25 °C), the electrical conductivity for 0.025 Mol/Lit is about 2807.57 μS/cm, for 0.5 Mol/Lit is about 31677.92 μS/cm while it is increased to about 37242.09 μS/cm for the electrolyte concentration of 1 Mol/Lit. Comparing the results for the NaCl and that of H_2SO_4 electrolyte it is noted that at the same temperature and concentration, H_2SO_4 electrolyte has a much higher electrical conductance rather than of NaCl solution.

In Fig.5 comparison of the electrical conductivity of water liquid (distilled and municipal) and a typical electrolyte solution (NaCl, 0.025 Mol/Lit) is given at room temperature (25 °C). As can be seen the NaCl electrolyte solution has a conductance value of 2807.57 μS/cm much higher than that of typical distilled water (19.99 μS/cm at 10 ppm) and municipal water (1000 μS/cm at 500 ppm). The physical reason for such a high conductance value can be described as following. In ionic compound, entire ion may diffuse to conduct electricity, though these ions may have very low mobility. Appling a potential to a liquid conductor causes current to flow through solution by dissolved particles (ions) that have electrical charges. Usually dissolved ions move slower than electrons, depending on their geometry, potential, and the temperature of solution. Generally smaller ions move through a solution more rapidly than larger ones. As discussed, in water the hydrogen ion (H^+) and the hydroxyl ion (OH^-) are extremely mobile due to their geometry and size of ions relative to each other in comparison with the Na^+ and Cl^- ions in NaCl aqueous solutions. As a result, NaCl shows a much higher conductance value in comparison with that of water liquid. Same argument about higher value of electrical conductivity in comparison with the water liquid can be given for other electrolytes.

As described there is a relationship between the conductivity and concentration of electrolytes. Different solutions with different conductivities do not always show a direct relationship proportional to concentration of salts or solids in solution. In dilute solutions, an increase in concentration causes a linear increase in conductivity provided that there are no interactions between the solution and the dissolved electrolyte. When these conditions are met, the dissolved electrolyte is said to be completely dissociated. An example is sodium chloride. Thus, investigating concentration versus conductivity provides an important physical property of solution. As mentioned, sulfuric acid (H_2SO_4) can be completely dissociated and its conductivity is directly proportional to its concentration. For this solution the H_2SO_4 dissociates to form $(H)^+$ and $(HSO4)^-$ ions and for the given low concentration, a gradual increase of electrical conductivity with the concentration is noticed. As can be seen in Fig.4, a similar pattern is noticed for the NaCl electrolyte.

In experimental measurements, the resistance and capacitance of different water samples are measured at a fixed temperature and a frequency of 1 kHz using either short or long cell probe, respectively. Such measured values for the long probe are listed in Table2 and for short probe in Table3. Different samples including distilled water (DW) mineral water (MW), tap water (TW), boiled water (BW), and two dilute solutions of salt waters with different salt concentrations (SW1,SW2) are tested. The conductivity and the TDS values for the given samples are measured with the EC meter.

In order to compare the parameters of the experimented water samples with the developed model for the conductivity computations in Table1 the results of the measured EC values with the EC meter are compared with the calculated values. The TDS values are also measured for the given sample at the temperature of 20.6 ˚C. To the comparison of the measured values with the theoretical ones the assumed concentration of the samples with the temperature 20.6 ˚C are also listed in Table 1. As can be seen the experimented distilled water matches the distilled water sample with a concentration of 1.9 ppm, mineral water with an impurity level of 122.5 ppm, tap water 174.5 ppm, and finally boiled water with an impurity of 187 ppm. For the electrolyte such as NaCl the molar concentration is assumed at the given temperature. The measured EC for the salt-water solution denoted as SW1 is about 0.0162 Mol/Lit while for the salt-water solution SW2 is about 0.03125 Mol/Lit.

In Fig.6 the measured electrical conductivity values are compared with the calculated ones based on the assumed impurities and concentrations shown in Table1. As can be seen with e assumed impurities there is a good agreement between the measured and calculates ones. As can be seen in Fig.6, as expected the electrical conductivity for the DW is the lowest while for the dilute solution of the NaCl is the highest. A similar behavior as observed in the theoretical computations as shown in Fig. 5. On the other hand, as shown in Fig.5, for calculation for electrolyte such as NaCl solution the EC value is very sensitive to the concentration. As can be seen in Fig.6, for the SW1 which is more dilute than SW2 the EC value is accordingly lower (compare 1693 μS/cm with 3140 μS/cm).

Table 1: Comparison of the electrical conductivities for different samples.

Water Sample	TDS(mg/L), ECT=20.6˚C	g (µS/cm)EC, Exp.T=20.6˚C	g´(µS/cm) Theo.T=20.6˚C	Assumed Concentration Theory
Distilled	1.70	3.41	3.441	1.9 ppm
Mineral	111.4	223	223.38	122.5 ppm
Tap	158.8	318	318.212	174.5 ppm
Boiled	170.6	341	341.006	187 ppm
Salt Water1	846.0	1693	1693.67	0.0162 Mol/Lit
Salt Water2	1572.0	3140	3140.197	0.03125 Mol/Lit

*g: Conductivity with EC Meter, g´: Conductivity from theory

Table 2: Parameters obtained with the short cell probe.

Water Sample	R (Ω) T=15˚C	C (µF) T=15˚C	Relaxation Time t_c=RC (ms)	g(µS/cm) ECT=20.6˚C	Permittivity Im. (ε)×10^{-7} (F/m)T=15˚C
Distilled	2386.2	2.91	6.94384	3.41	23.6784
Mineral	42.86	12.03	0.51548	223	114.9520
Tap	30.17	12.07	0.36415	318	115.7997
Boiled	27.98	12.54	0.35086	341	119.6432
Salt Water1	7.32	14.73	0.10782	1693	182.5392
Salt Water2	4.64	15.17	0.07038	3140	220.9932

From Eq. (11) it was shown that the ratio of permittivity to conductivity is equal to the product of the CR value. In this experiment using LCR module both C and R measured and such products for the long and short cell probes are shown in Fig.7. As described such relation time the measure of the conduction relaxation and for a good conductor such time is very short. As can be in Fig.7, the relaxation time for salt solution is about 0.07044 ms (0.07038 ms for short probe) for boiled water 0.355 ms (0.350 ms), for TW 0.374 ms (0.364 ms), for MW 0.524 ms (0.515 ms), and finally for the distilled water is about 8.059 ms (6.943 ms). From obtained results it is noted that for the salt water solution takes a very short time of about 0.07 ms to establish a stabilized conductorlike behavior while for the distilled water a longer time of about 8.059 ms is required to reach such a condition. As expected the results clearly shows the conductance effect of the tested liquid samples. Also as can be seen except for the distilled water the relaxation time for the two probes are very similar, which indicates such given values are predominated by the conductance of the filled liquids rather than the probe length. However such time relation for the long probe is higher since the volume of the filling is higher for the long cell probe. If we measure the conductivity by another instrument then by using RC product valued we can compute the imaginary part of the permittivity values for different liquid samples, see Eq.(11). Such measurements are performed with EC sensor and the related permittivity are computed and listed in Table 2 for the short sensor. In Table 3 similar results are given for the long probe cell. As can be seen in Table 2 the permittivity for the DW is the minimum value of about 23.67×10^{-7}(F/m) while for the salt water 2 solutions is the highest vale 220.99×10^{-7}(F/m). A similar increasing pattern is noted in the measurements performed by the long probe as indicated in Table 3. The imaginary parts of the permittivity (ε'') of the tested samples are shown together in Fig.8. A can be seen a similar results are obtained for the short and long probes for the corresponding samples. It is also noted that the imaginary part of the permittivity for the tested water samples are much higher than the real part, which shows the conductivity term is dominating the permittivity or the dielectric capacity in the reported measurements.

Table 3: Parameters obtained with the long cell probe.

Water Sample	R(Ω) T=15˚C	C (µF) T=15˚C	Relaxation Time t_c=RC (ms)	g(µS/cm) ECT=20.6˚C	Permittivity Im. (ε)×10^{-7} (F/m)T=15˚C
Distilled	1217.4	6.62	8.05918	3.41	25.30582
Mineral	22.05	23.87	0.52479	223	117.028
Tap	14.95	25.04	0.37434	318	119.041
Boiled	13.57	26.21	0.35566	341	121.2459
Salt Water1	3.50	31.09	0.10881	1693	184.2153
Salt Water2	2.20	32.02	0.07044	3140	221.1816

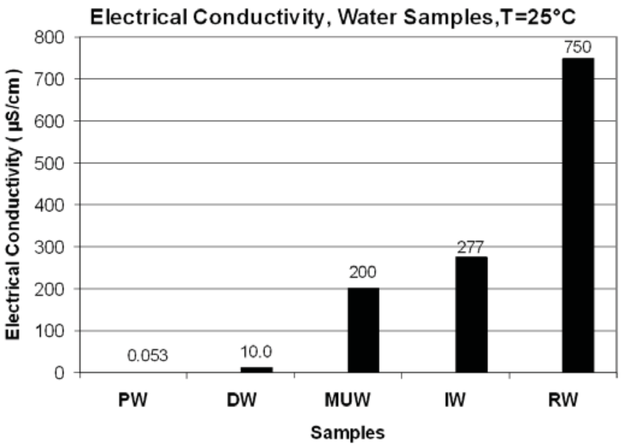

Fig. 2: Computed electrical conductivities for different water liquids. Samples indicated as PW (Pure Water), DW (Distilled Water, 5 ppm), IW (Industrial Water, 100 ppm), RW (River Water,100 ppm) and MW(Municipal Water,100 ppm).

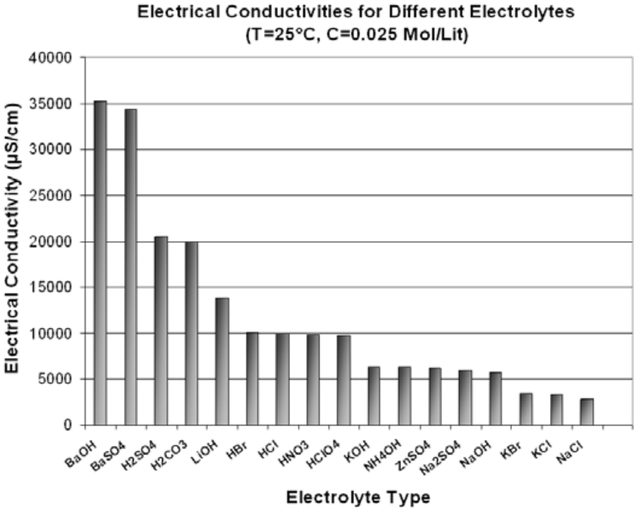

Fig. 3: Computed electrical conductivities for different electrolyte solutions.

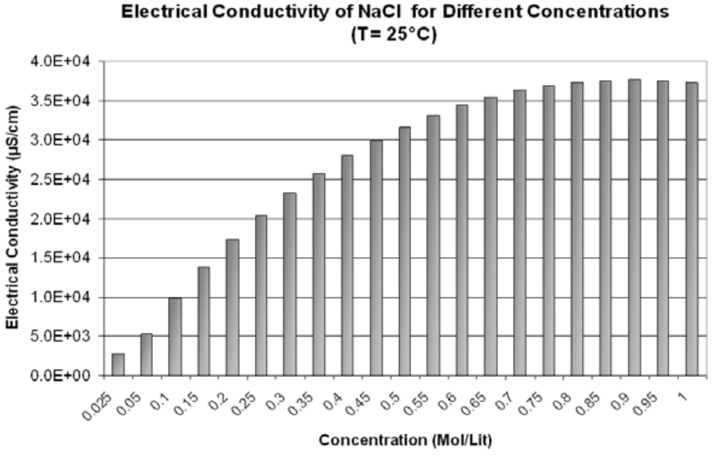

Fig. 4: Variation of the electrical conductivity for the NaCl electrolyte solution.

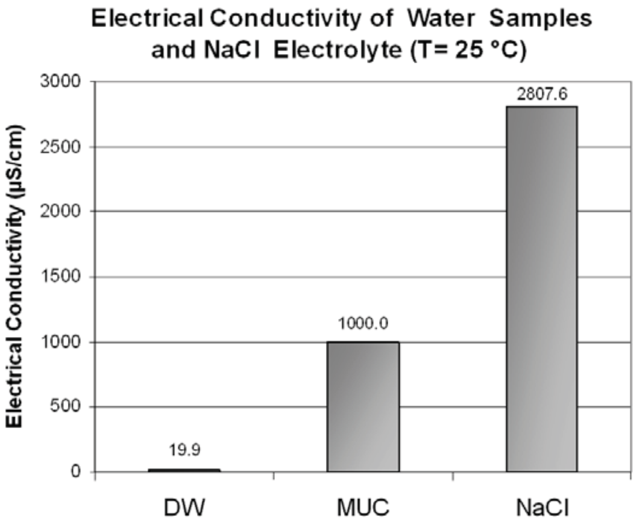

Fig. 5: Comparison of the theoretical conductivities for water sample and NaCl solution.

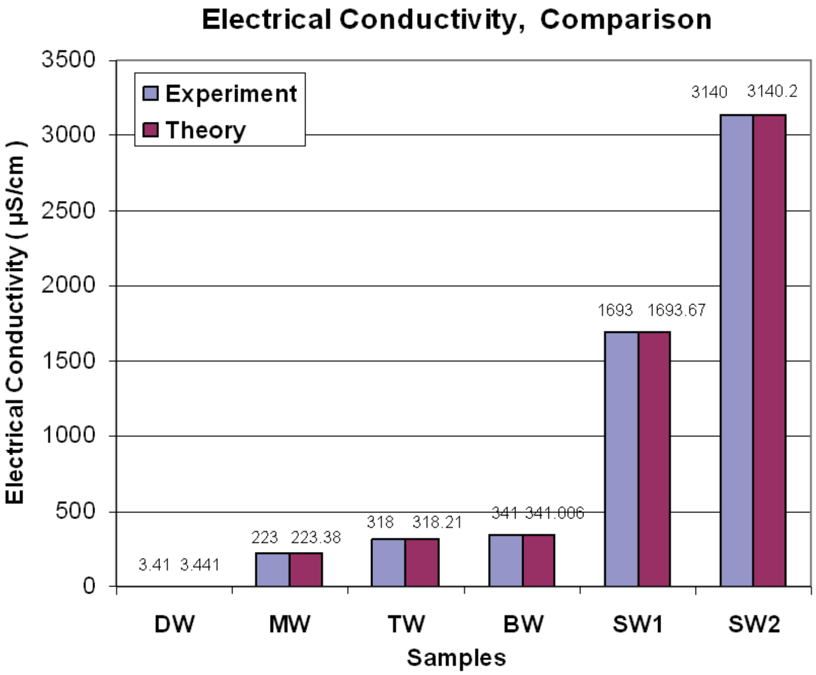

Fig. 6: Comparison of the experimental and theoretical conductivities for different samples.

Conclusions:

A theoretical model for computation of electrical conductivity of water and electrolytes are reported in this study. Based on the developed algorithms different programs are written that easily outputs the conductivity values according to the given input parameters. Parameters such as substance temperature and impurity play important roles in the determination of the electrical conductivity and results for the concentration variation for given substances are compared in this study. By measuring the resistance and capacitance values simultaneously,

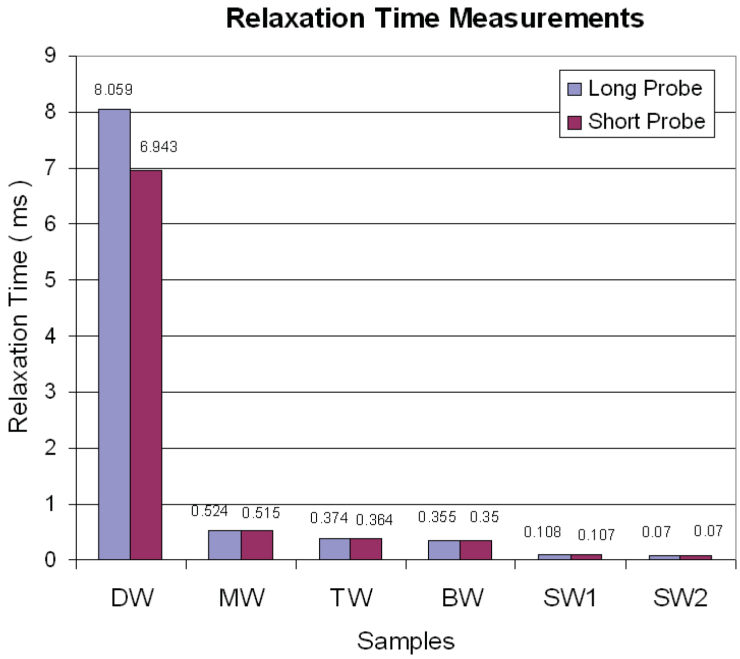

Fig. 7: Time constant values for different water samples.

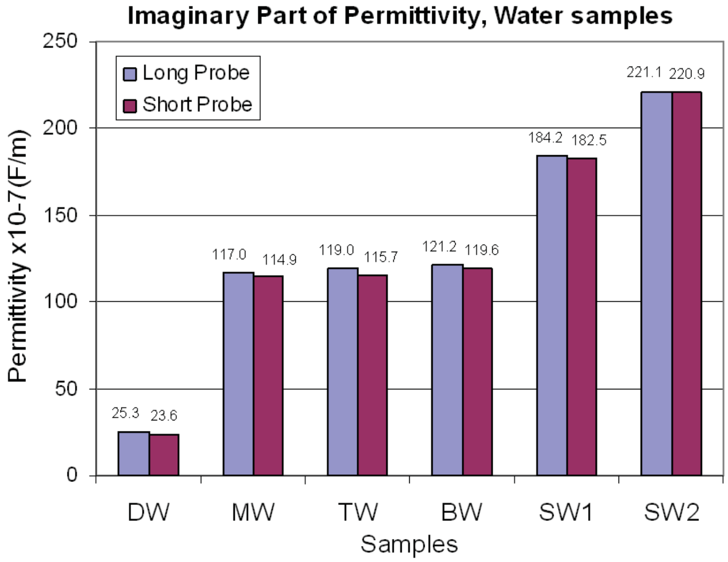

Fig. 8: Comparison of the imaginary part of the permittivity values for different samples.

the relaxation time s for different water samples are measured experimental. Variation of such time constant for different samples is described in this investigation. In another measurement the electrical conductivity of different samples are measured by a EC meter and by knowing the conductivity and time constant the imaginary part of the permittivity are determined at frequency of 1 KHz for different water samples. Our results show that the imaginary part of the permittivity is much higher than the real part, thus the reported method is a very effective way to study the electrical conductivity of different water samples and dilute electrolytes.

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