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Efficacies of Dissolved Substances on the Electrical Conductivity of Liquids

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ABSTRACT

This work studies the efficacies of dissolved substances on the electrical conduction in liquids to establish the causes of electrical conduction in liquids. The study aimed to identify the constituents of liquids and the factors that facilitate conduction in them. To achieve this aim, the electrolysis method was applied. The electrical conductivity (EC) meter was calibrated by following the manufacturer's instructions, using a standard solution of known electrical conductivity. Probes were thoroughly rinsed with distilled water and dried with kinwipes between tests. A 250ml beaker was rinsed with distilled water, and 100ml of distilled water was placed in the clean beaker. The electrodes were submerged completely into the water. The electric conductivity meter was activated, and allowed to stand for about a minute to stabilize. The conductivity reading in mS/cm was recorded as the reference conductivity value (at zero concentration). Next, 100ml of distilled water was placed in another 250ml clean glass beaker. 0.1g (100mg) of sodium chloride was dissolved in the distilled water, and the electrical conductivity was measured and recorded. This procedure was repeated for various concentrations of sodium chloride: 0.2g (200mg), 0.3g (300mg), 0.4g (400mg), 0.5g (500mg), 0.6g (600mg), and 0.7g (700mg). In each case, the electrical conductivity reading was noted. It was observed that liquids, including water, are poor conductors of electricity. However, when impurities such as salts are added, they can conduct electricity much more effectively. Ultimately, it was noted that when sodium chloride was dissolved in distilled water, the solution became a conductor of electricity, with higher salt concentrations resulting in higher electrical conductivity.

Keywords:
Anode
Cathode,
Conductors,
Electroplating,
Electrolysis,
Insulators,
Oxidation,
Reduction.

INTRODUCTION

It is an already established fact that electrical conduction occurs in liquids. This therefore necessitated the investigation of the effects of dissolved substances on the electrical conduction in different liquids. The study established the causes of the electrical conduction in those liquids, because, ordinarily, liquids are good insulators of electric current, it as well established the constituents of liquids and the things that necessitate conduction in liquids. Furthermore, the work was investigated by looking at atoms, its compositions and its contributions to the conduction of electric current in liquids. It was further examined the applications of the electrical conductivity in liquids, taking critical look at electrolysis of liquids and its applications in electroplating. It also examined electroplating and its applications in the industries to justify the significance of the work.

Generally, conductivity is a measure of the amount at which an electric charge (current, or heat (thermal energy), can pass through a material. Conductivity is the inverse of resistivity, where resistivity is defined as the resistance of 1 meter cube of the material (Geddess, 1981). The resistivity of a material is based on the resistance of a defined volume of that material (Schuler and Fowler, 1993). Ugwu et al (2013), defined resistivity with symbol, as the resistance R of unit length L of material of unit cross-sectional area A, the unit of resistance is the (ohm), and it is expressed as;

$$R = e\frac{L}{A}(SD) \quad (1)$$

Where;
R = Resistance of the material (Ω)
E = Resistance of the material (Ω.cm)
L = Unit length of the material (m)
A = Cross-Sectional area of the material (m^2)

The conductivity of a material u represented by the Greek letter, Sigma (∂) since it is the inverse of resistivity is simply as the inverse of resistivity which is called conductivity (Schular and Fowler, 1993) and the letter symbol for conductivity is ∂ (the Greek letter signma), so that conductivity is mathematically expressed as;

$$\partial = \frac{1}{e} \quad (2)$$

In the S.I. System of Unit, conductivity is expressed in siemens per metre (s/m), (Schuler and Fowler, 1993).

The material medium through which this energy (electrical or thermal), is transmitted is called conductor. So, a conductor is a material which presents very little opposition (resistance) to the flow of an electric current, or thermal energy (heat).

Electric conductivity refers to the measure of how electric current moves within a substance, (Topper: https://www.topper.com). in very simple words, electrical conductivity is the ability of conducting electricity. In the beginning, electricity was thought of as the flow of electrons through solid conductors, in the form of wire, and this flow is called an electric current. However, many processes depend on electrical current flowing through a gas or liquids. (Herman, 1993). Devices like batteries, fluorescent lighting among others, would not work if there is no conduction in liquids and gases.

Understanding of the phenomenon of electricity and electrical conductivity through substances can be made a lot easier by a little knowledge into the structure of an atom. The atom is the basic building block of the universe (Herman, 1993). All matters are made up of atoms (LEONICS). From basic physics, atoms are the smallest part of an element. All matters are made from a combination of atoms. Matter is any substance that has mass and occupy space. Matter can exist in any three states: solid, liquid or gas. On the other hand, an element is a substance that cannot be chemically divided into a simpler substance. As stated above, an atom is the smallest part of an element. The three principal parts of an atom are electron, neutron and proton. The proton and neutron combine to form the nucleus of the atom, while the electrons revolve (orbit) around the nucleus. Each orbit of an atom contains a set of number of electrons. The number of electrons that can be obtained in any one orbit or shell, is found by the formular $2N^2$ (Herman, 1993), and the letter N represent the number of the orbit or shell. For example, in the first orbit of any atom, the number of electrons is $2(1)^2 = 2 \times 1 = 2$ electrons.

The orbital electrons contribute greatly in the conduct of electric current through materials. The outermost electrons of an atom, i.e. those in the shell further mostly from the nucleus are called valence electrons and have the highest energy, or heat binding energy (Theraja and Theraja, 2008). It is these electrons which are mostly affected when a number of atoms are brought very close together during the formation of a solid. The band of energy occupied by the valence electrons is called the valence band, and is, obviously, the highest occupied band, it may be completely filled with electrons but never empty, the next permitted energy band is called the conduction band and may either be empty or partially filled with electrons, it may as a matter of fact be defined as the lowest unfilled band.

In conduction band, the electrons can move freely, and are known as conduction electrons. The gap between these two bands is known as the forbidden energy gap. If therefore, a valence electron happens to absorb enough energy, it jumps across the forbidden energy gap and enters into the conduction band. So, an electron in the conduction band jump to an adjacent conduction band more readily than it can jump back to the valence band from where it came earlier, although, if the conduction electron happens to radiate too much energy, it was suddenly reappear in the valence band once again. The ability of the valence electrons to play a role in the conductivity of electro current depends largely in the type of materials.

The electrical conduction properties of different elements or materials or compounds can be explained in terms of the electrons having energies in the valance and conduction bands. The electrons lying in the lower energy bands, which are normally filled, play no part in the conduction processes.

Materials are therefore classified into three major categories depending on their level of permit to flow of electrons. These classes of materials are; the insulators, conductors and semiconductors. (Theraja and Theraja, 2008).

Insulators are those substances which do not allow the passage of electric current through them (Mehta and Mehta, 2008). Their valence electrons are bound very tightly to their parents atoms, thus requiring very large electric field to remove them from the attraction of their nuclei (Theraja and Theraja, 2008). In other words, insulators have no free charge carriers available with them under normal conditions. In terms of energy band, it means that insulators have full balance band, have an empty conduction band, have a large energy gap of several electron volts (ev), between them, and at ordinary temperatures, the probability of electrons from full valence band gaining sufficient energy so as to surmount energy gap and thus, become available for conduction in the conductor band which is slight.

A conductor on the other hand, is generally made from a material that contains one or two valence electrons, and atoms with one or two valence are unstable and can be made to give up these electrons with little effort (Herman, 1993). Conductors are materials that permit electrons to flow through them easily. When an atom has only one or two valence electrons, these electrons are loosely held by the atom and are easily given up for current flow. For example, silver, copper, and gold all contain one valence electron and are excellent conductors of electricity (Herman, 1993). Silver is the best natural conductor, followed by copper, gold and aluminum. Conductors therefore conduct or permit the flow of the electrons easily. The simple explanation being that when an atom contains only one valence electron, that electron is easily given up when struck by another electron. The striking electron gives its energy to the electron being struck (valence electrons). While the striking electrons settles into the orbit around the atom, the electron that was struck moves off to strike another electron. Similarly, if an atom containing two valence electrons is struck by a moving electron, the energy of the striking electron will be shared between the two valence electrons and they are knocked out of the orbit, they will contain only half the energy of the striking electrons. Good electric conductors therefore contain many free electrons.

The other class of materials that need to be mentioned here is the semiconductor. Semiconductors are materials that are neither good conductors nor insulators (Herman, 1993). These materials contain four valence electrons and are characterized by the fact as they are heated their resistance decreases. Heat has the opposite effect on conductors whose resistance increases with increase of temperature of electricity that occurs in liquids and gases. However, conduction of current through liquids, or gas does not depend on the flow of individual electrons as is the case with metallic conductors (Herman, 1993).

Conduction in gases and liquids depends on the movement of ions. Ionization have been used to make materials that are normally electrically inactive to be active (Schuler and Flowler, 1993). When various salts dissolve into water, they will turn into positively and negatively, charged ions (Sensorex, 2016). The positively charged ions that can affect water include potassium, magnesium, and sodium, among others, while the negatively charged ions that can affect water include carbonate, chloride, and sulfate. However, salt is not the only compound that can be used to promote conduction in liquids (Herman, 1993). Acids, alkalis, and other types of metallic salts can be used and these solutions (the substances in water) are referred to as electrolytes.

The presence or dissolution of certain substances in water presents certain effects on water, some of the effects can be positive, while some can be negative. The electrical conductivity of water refers to how well, water is able to conduct electricity (Sensorex, 2016). Generally, liquids (water) are good insulators and so they drive the least possible electrical current when voltage is applied to it. (Assia Shita et al, 2016). The conductivity σ of liquids (water) should be as low as possible. Conversely, its resistivity ġ(Ω.cm), must be as strong as possible. The resistivity of liquids can therefore be influenced by the presence of foreign substances such as the salts, acids, alkalis, etc. mentioned earlier, which can be considered as impurities. On the other hand, charges introduced by dissolving compounds in the water are responsible the conduction of electricity in liquids. In water, the chemical bond of the foreign or impurity compound breaks into numerous atoms carrying positive or negative ions or charges.

The freely moving charges flow, resulting in the electrical conductivity. The compounds that break up into charges when introduced into water are called ionic compounds (Herman, 1993). However, the knowledge of electrical conductivity (EC) of water is very important for numerous industrial applications. With the knowledge of electrical conductivity in water, one can tell how much dissolved substances, chemicals and minerals that are present in the water. Higher amount of impurities (dissolved substances), will lead to a higher electrical conductivity. Even a small amount of dissolved salts and chemicals can lighten the conductivity of water. Furthermore, when electrical conductivity of water is higher, it can attract electricity. It is based on this that it is dangerous to use a smartphone while taking a boat, or going for a swim while thunderstorm is ongoing. The electrical conductivity of water can also be used to determine the effect of the water on some processes like cooking towers and boilers.

Ordinarily, pure water has an extremely low electrical conductivity because of lack of impurities (dissolved substances), within it. However, when various chemicals and dissolve into water, they will turn into negatively, and positively charged ions. The electrical conductivity value of such water can be used to determine to a great extent, the quality of the water. For instance, the electrical conductivity of pure (drinking) water should be less than 1 micro-siemens/cm (1mS/cm), while that of sea water that has ample amount of salts and other chemicals is believed to be between 45-72mS/cm (Sensorex 2016). Electrical conductivity of liquids (water and other chemicals) is utilized in electroplating of metals. Electrical conductivity in liquids can therefore be of immense benefits in the industries for electroplating. When some substances are dissolved in water and electric current is applied in the water, it causes the flow of current which leads to the deposition of atoms of one type of metal on another. This phenomenon involves two very important processes known as "electrolysis and electroplating".

MATERIALS AND METHODS

Materials

The major materials used in this research are battery, molten NaCl, anode, cathode, beaker, and water. Relevant journal publications were equally used.

Methods

Using the materials and apparatus/instruments, the setup was implemented as shown in figure 1

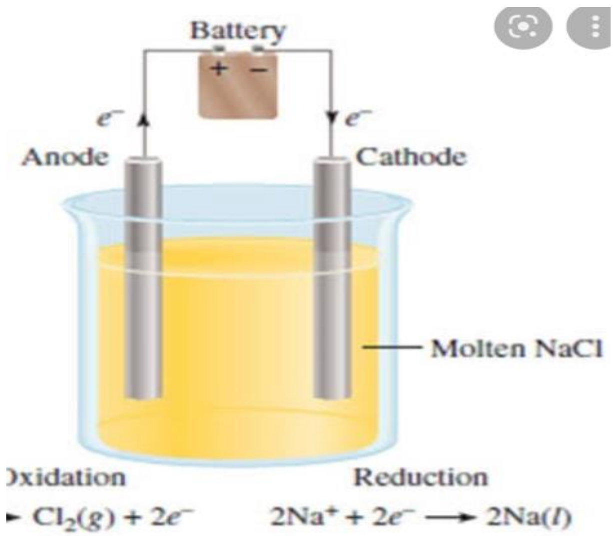

Figure 1: Setup for the investigation of the effects of dissolved sodium chloride distilled water

The electrical conductivity (EC) meter was turned on to calibrate the probes, in accordance with the manufacturer's instruction; using standard solution of known electrical conductivity; ensuring that the probes were thoroughly rinsed used with distilled water and dry with kinwipes in between tests. The meter itself was calibrated for temperature compensation using temperature compensation Knob on the EC meter. The smaller beaker (250mol) was properly rinsed with distilled water 100ml of distilled water was placed in the clean beaker and the electrodes inserted into the water so that they are submerged completely. The electrical conductivity meter was then switched on, and the meter reaching allowed to stand for about 1 minute to stabilize. The meter conductivity reaching in MS/CM was read and recorded the as the reference conductivity value (at zero concentration). 100ml distilled water was placed in another 250ml clean glass beaker. 0.1g (100mg) was dissolved in the distilled water, and EC measured and recorded. This procedure was repeated for more concentrations of the solution with 0.2g (200mg), 0.3 (300mg), 0.4g (400mg), 0.5(500mg), 0.6g(600mg) and 0.7(700mg) of sodium chloride, and in each case, the electrical conductivity reading was recorded as in the table.

RESULTS AND DISCUSSION

The results of the measurements obtained are shown in table 1 below, which shows the value for the electrical conductivity measured with the corresponding chloride concentrations.

Table 1: Value for the electrical conductivity measured with the corresponding chloride concentrations

Concentration of sodium chloride solution (g/100ml)	Conductivity of the solution µS/Cm
0.00	0.00
0.10g (100mg)	150.00
0.20g(200mg)	450.00
0.30g (300mg)	750.00
0.40g (400mg)	850.00
0.50g (500mg)	950.00
0.60g (600mg)	1050.00
0.70g (700mg)	1200.00

A plot of conductivity against the solution concentration was made using the data in table, Fig 2 shows the plot of the conductivity (NS/cm) against the concentration of sodium chloride solution (g/100ml)

Plot of conductivity against concentration of sodium chloride solution, number of drops added, molarity and conductivity of sodium chloride and acetic acid.

Table 2: Molarity and conductivity of sodium chloride and acetic acid

Drops added	Molarity	Sodium Chloride conductivity (MS/CM)
0	0	1
1	0.000571429	74
2	0.001142857	154
3	0.001714286	244
4	0.002285714	366
5	0.002857143	435
6	0.003428571	524
7	0.004	593
8	0.004571429	660

Fig. 2 equally shows the relationship between concentration and conductivity of sodium chloride and acetic acid

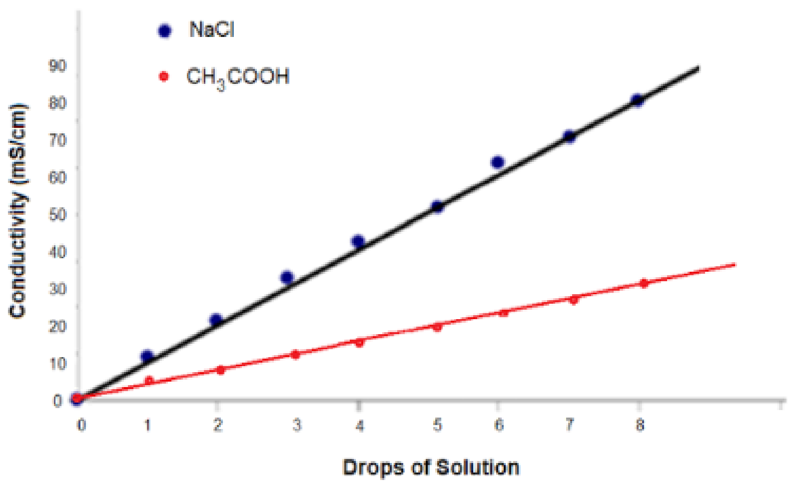

Figure 2: Conductivity as a function of concentration

Using the plots and the data above, the study calculated.
Calculation
Volume = 1.2ML
Average volume per drop = 1.2ml/30drops = 0.04ml/dg
Molarity = (4×10^{-5}mol NaCl/drop) (1drop/70ML/Litre)
= 5.7×10^{-5} NaCl

Discussion

The results of this study showed that as the number of drops increases and the concentration due to that increases, the conductivity increases for sodium chloride for instance from the table, it can be seen that as the drops increased from O to 8, drops the conductivity increases from O to 660µS/cm. similarly, as the drop of Acetic acid increases from O to 8, drops, the conductivity of the acetic acid increases from 2 to 97, from the graph, it can be seen that the slope of NaCl conductivity was much stepper than the slope for Acetic Acid conductivity. This finding is in agreement with Golnabi et al (2009), who suggested that the electrical conductivity of water, including both distilled and municipal varieties, compared to a typical electrolyte solution like NaCl at a concentration of 0.025 Mol/L, shows significant differences at room temperature (25 °C). The conductance value for the NaCl solution was identified to be much higher in comparison to distilled. This highlights the increased conductivity in electrolyte solutions compared to pure or lightly mineralized water.

Furthermore, the study noted that an increase in the concentration of a solution affects the conductivity. Sodium chloride is a strong electrolyte and so, when it is dissolved in a solution, it completely dissociated into its various ions (Na^+) and (CL^-) ions. So when more drops are added, concentration of the ions increases and the conductivity increases in response. However, Acetic acid is a weak electrolyte and when dissolved in solution, it doesn't completely dissociate, so that as the drops is increased, thereby increasing its concentration, its conductivity increased but very little. This implies that having both strong, and weak electrolytes the strong electrolyte's conductivity will increase at a faster rate than the weak electrolyte.

In the current study chloride in pure water, on the electrical conductivity of the solution is being investigated. The distilled water showed no electrical conduction. Pure water is a poor conductor of electricity. The distilled water contained no conductive ions and therefore showed no conductive behavior when the electrical conductive meter was connected across it, However, when salt and other impurities or contaminants in water dissociates into components called ions, the distilled water can then conduct electricity and thus, becomes a good conductor of electric current.

As it has been observed in this investigation, when sodium chloride was added to the distilled water, there was conduction as recorded by the conductivity motor. As shown in figure 4.1 (plot of conductivity against concentration increases with increasing salt concentrations in the solution. So with the presence of dissolved impurities sodium chloride (NaCl), the water's insulation resistance or dielectric constant of 80, permits the sodium ion (Na^{+}) and the chloride ions (Cl^{-}) to move freely through the liquid, and promotes an account for the change in the conductive behavior of the distilled water in the situation above, the sodium atom is converted into sodium ions and the chlorine atoms are equally converted into chloride ions.

Since the conductivity increases as the NaCl concentration in the water increase it then means that the sodium chloride (NaCl) concentration has a linear effect on the conductivity value of NaCl solution, so that the higher, the sodium chloride concentration, the higher the conductivity of the solution. Another very important revelation the study has given in the issue of solution saturation.

From the graph, it could be seen that at very higher concentration of sodium chloride (NaCl) ion the solution, say at about 700mg (0.7g), the curve tends to descend. It was no more linear as it was tending to curve down wards. This indicates that the solution was getting saturated and no more ionic increase.

CONCLUSION

Liquids including water are very pore conductors of electricity. However, a lot of processes depend on the conduction of electric current through liquids. Liquids therefore need to be conditioned to enhance electrical conduction through them. This study has therefore shown that when impurities such as salts are added into liquids, it can conduct electricity very excellently. So the effects of dissolved substances in the electrical conductivity of liquid is that such liquids become enhanced to conduct electric current when these impurities are dissolved in them. Consequently, when sodium chloride is dissolved in distilled water, the distilled water became a conductor of electricity, and the higher the concentration of the salt, the higher the electrical conductivity of the solution.

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