Studies on Electrical behavior of Glucose using Impedance Spectroscopy

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Abstract. In this work we report the electrical characteristics of glucose at different frequencies. We show the correlation between electrical properties (impedance, reactance, resistance and conductance) of glucose and glucose concentration. Electrical property measurements on glucose solution were performed in order to formulate the correlation. The measurements were conducted for frequencies between 50 Hz and 1 MHz. From the measurements, we developed a single-pole Cole-Cole graph as a function of glucose concentration.

1. Introduction

Glucose is a very important material in various aspects of life. In food technology, glucose is often used as a food sweetener. Glucose content in fruits is one of the determining factor in taste and quality. In Yeast cells, glucose also trigger unexpected, hormone-like effects, including the activation of cellular growth, the mobilization of storage compounds and the diminution of cellular stress resistance \cite{1}. In medical science, regulation of glucose content in the blood is an important role for diabetic patients \cite{2}. Glucose is used as an energy source in most organisms, from bacteria to humans. Use of glucose may be by either aerobic respiration, anaerobic respiration, or fermentation. Glucose is the human body's key source of energy, through aerobic respiration, providing approximately 3.75 kilocalories (16 kilojoules) of food energy per gram\cite{3}.

The electrical impedance spectroscopy provide important information on ion-ion and ion-solvent interactions \cite{4}, such as limiting molar conductivity and the ion pair formation constant of Ammonium Bromide \cite{5}, specific conductivity of solution of sodium chloride in pure water and ethanol water mixed solvent media \cite{6}. Impedance spectroscopy has been proposed as possible approach for non-invasive glycaemia monitoring. Other applications require the measurement of total dissolved solids (TDS), which is related to conductivity by a factor dependent upon the level and type of ions present \cite{7}. However, few quantitative data are reported about impedance variations related to glucose concentration variations, especially below the MHz band \cite{8}. This research will be assessed

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on the electrical characteristics of glucose for various frequencies in the low electrical signals. It aims to examine the electrical behavior of glucose as the data base information for the benefit of other advanced.

2. Results and Discussions

Soluble Solid Content of Glucose Solution

Glucose is a carbohydrate, and is the most important simple sugar in human metabolism. Glucose is called a simple sugar or a monosaccharide because it is one of the smallest units which has the characteristics of this class of carbohydrates. Glucose is one of the primary molecules which serve as energy sources for plants and animals. It is found in the sap of plants, and is found in the human bloodstream where it is referred to as "blood sugar". Total soluble solids of fruit such as sweet orange, mandarin, grapefruit, and pummelo juices constitute mainly sugars. TSS of citrus juices indicates all the soluble solids. It is not a measure of sugars only [9] Other applications require the measurement of total dissolved solids (TDS), which is related to conductivity by a factor dependent upon the level and type of ions present [7]. So, it is necessary to test the correlation between TSS and glucose concentration in the sample used in this study. Figure 1 shows the results of the linear correlation for the glucose concentration in the sample solution and TSS parameters. The figure shows that the increase in glucose concentration will increase the value of TSS. This occurs in a linear relationship with a high coefficient determinant ($R^2=0.9991$).

**Figure 1.** Correlation between glucose concentration and TSS parameters in the sample solution.

Electrical Impedance of Glucose Solution

Any electrode–material system in a measuring cell has a geometrical capacitance and a bulk resistance in parallel with it. Electrical impedance ($Z$) is defined by a complex quantity in terms of resistive ($R$) and capacitive ($C$) components as $\left[ Z \right] = \sqrt{(Z')^2 + (Z'')^2}$, where $Z'' = \left[\omega C(\omega)\right]^{-1}$ and $Z' = R$. It is only real when $\omega = 0$ and thus $Z = Z'$, that is, for purely resistive behavior. In this case the impedance is completely frequency-independent. When $Z'$ is found to be a variable function of frequency ($Z'(\omega) = R(\omega)$) which holistically connect real and imaginary parts with each other, ensure that $Z''$ cannot be zero over all frequencies but must vary with frequency as well.

In essence, dielectric studies are based on quantifying the response of a material to an electric field applied to it. The response is typically described by the material’s conductivity and permittivity. Conductivity ($\sigma$), measured in S/m, quantifies the ability of the material to conduct the electrical charge. Permittivity ($\varepsilon$), measured in F/m, is the amount of charge that is stored by the
material due to the polarization of its components. Permittivity of the material is often expressed as relative to the permittivity of vacuum \((\varepsilon_0=8.854 \times 10^{-12} \text{ F/m})\), giving the dimensionless relative permittivity (also called dielectric constant), \(\varepsilon_T=\varepsilon/\varepsilon_0\). By dividing conductivity and permittivity by the probe constant \((d/A\text{ in m}^{-1})\), the ratio of the distance between the electrodes and the electrodes’ area, one obtains the corresponding conductance \((G\text{ in S})\) and capacitance \((C\text{ in F})\) of the material, respectively. The permittivity of a material tends to fall (and its conductivity to rise) in a series of step-like shifts as the frequency of the electrical field rises. These step changes, called dispersions, are due to losses of certain characteristic polarization abilities of the substance.[10]

![Figure 2. Spectrum of electrical impedance in the sample solution.](image)

![Figure 3. Cole-cole mode in the sample solution.](image)
Studies on electrolytic impedance or conductance in mixed solvents can provide useful information and sensitive indications of ion-solvent and ion-ion interactions and solvent structure. The effect of ion association on the conductance behavior of electrolytes has been a subject of extensive investigation. Although numerous conductance measurements have been reported in the literature, such studies in mixed solvents are relatively rare [11]. In recent, several studies have reported that the nature of the spherical ions, having a large variation in size in aqueous mixtures of the alcohols, has received considerable attention.

On the other hand, it was recognized, that the sulfamate function is essential for cyclamate sweetness although the cation seems to have some effect on the sweet taste [10]. The behaviour of an ion in a solvent depends on the ion-ion and ion-solvent interactions. It is to be expected that the taste of a sweet substance could be interpreted by an understanding of these interactions in the medium.
3. Summary

We have performed electrical property measurements on glucose solution in order to formulate the correlation. We showed that the permittivity of a material tends to fall (and its conductivity to rise) in a series of step-like shifts as the frequency of the electrical field rises. These step changes, called dispersions, are due to losses of certain characteristic polarization abilities of the substance.

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