

STUDY ON THE EFFECT OF TEMPERATURE ON CALIBRATION PERFORMANCE OF SUCROSE IN AQUEOUS SOLUTION WITH RESPECT TO SUGAR CONCENTRATION

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Abstract

The calibration performance on sugar concentration in aqueous is shown to shift when absorbance is collected over a range of temperature relative to calibration developed at a single temperature. The aqueous solutions of sugar were prepared using high purity, laboratory chemicals (HPLC) reagent sucrose in grade-3 de-ionized water. The variation of absorbance against sugar concentration monitored at varied temperature was found to have positive nonlinear correlation. The temperature of sugar solution correlated well with absorbance features with PLS, R² found to be 0.810, 0.971, 0.973 and 0.980 for 5%, 15%, 25% and 40% concentrations respectively. This occurred due to the effect of temperature on mean kinetic energy and mean square displacement of sucrose particulates in the ambience.

Key words: shift, absorbance, nonlinear, temperature

1.0 Introduction

There are numerous methods for measuring the concentration of specific substances within a fluid. One such method is Electronic Spectroscopy (ES). Electronic Spectroscopy has been used in analytical chemistry for quantitative determination of different analytes (Skoog *et al.* 2003). This is due to electronic transitions that are responsible for the strong absorption of the UV-Vis spectral region of (200 nm – 780 nm) by biological materials (Mirta *et al.* 2003). Measuring the concentration of an absorbing species in a sample solution is accomplished by applying Beer-lamberts law (Skoog *et al.* 2007). From the result, Frank-Condon principle helps explain the intensity of vibronic transition that simultaneously changes the vibrational electronic quantum numbers due to absorption and emission of a photon (Misra and Mark, 2002).

According to the physical principle of Brownian motion, the mean kinetic energy of any molecule of a fluid is equal to of a particle suspended in this ambience. The of onward motion is given by;

$$\langle E \rangle = m \frac{\langle v^2 \rangle}{2} = \frac{3kT}{2} \dots\dots\dots 1$$

where m is the mass of the particle, v the velocity of the particle, k the Boltzman constant and T the temperature. With a random velocity, a Brownian particle will describe an irregular path, and will continually progress from its initial location. Calculations from previous studies (Narasimhan, 1999; Stachel, 2005; Lawler, 2006) have shown that the mean square displacement of a Brownian particle is described by the equation;

$$\langle r^2 \rangle = 6kTBt \dots\dots\dots 2$$

where B is the mobility of particle, which is inversely proportional to the medium viscosity and the size of the particle. We can see from equations 1 and 2 that, and of a Brownian particle is proportional to the temperature. It is therefore expected that sugar calibrations based on absorbance feature will be sensitive to temperature.

In the present paper, we study the calibration performance of sucrose in aqueous solution when absorbance is collected with respect to sugar concentration at a particular temperature. We further study the dependence of this absorbance over a range of temperature for a particular concentration and compare the results both quantitatively and qualitatively.

2.0 Materials and Methods

2.1 Preparation of sugar solution

Four aqueous sugar solutions of concentrations (in percentage) 5, 15, 25, and 40 were prepared. Mass of sugar was measured using an electronic balance – model XL-3100D, and solutions prepared using HPLC reagent sucrose in grade-3 de-ionized water. The mixture was stirred in a glass beaker to dissolve all the sugar granules to form a homogeneous solution. To ensure equilibrium, the solution was allowed to stand for 30 minutes and checked for sedimentation. The concentration was a measure of the amount of sucrose by mass in 100 g of the aqueous solution with de-ionized water.

2.2 Measurements of absorbance of sugar in aqueous solution with respect to temperature

The instrumentation used in this study was set up as shown in Plate 1. The neodymium-YAG (532 nm, 30 mW) radiation was illuminated on the sugar solution in the quartz cell. The cell (10 mm in width) was centrally placed between the light source and the photo-detector. The transmitted radiation was detected by 2N3904 photo transistor. The generated photo current (i_{ph}) is processed by the LM741CN transimpedance amplifier (TIA) and an output voltage (V_o) was displayed on a digital voltmeter – model H27763. This output voltage V_o , was a function of the transmitted light intensity. The instrument was zeroed to calibrate it by passing the incident radiation through a blank cell containing on the de-ionized water.

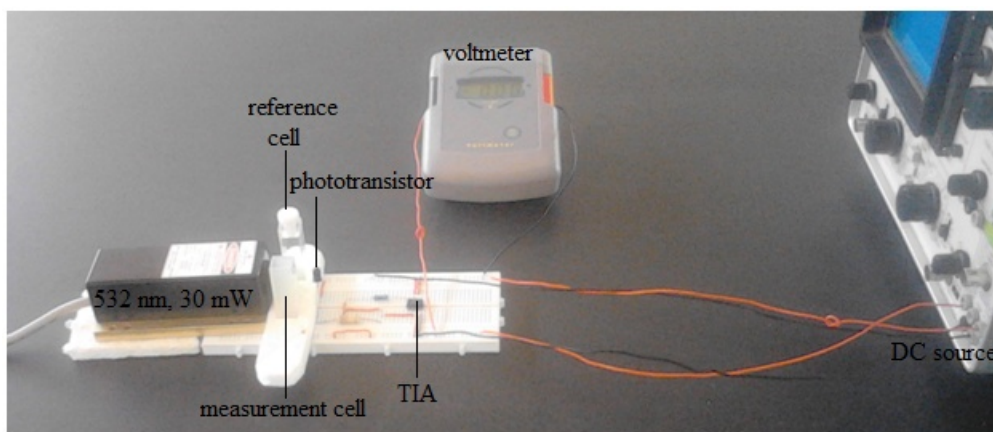


Plate 1: The experimental arrangement set up to measure transmittance of sugar in their aqueous solution.

The calibrated instrumentation was used to measure transmittance in sugar solutions using the neodymium-YAG (532 nm, 30 mW) laser radiation in dark room. Transmittance of sugar solution was measured in a quartz cell against de-ionized water as the reference solution for all measurements. This transmittance was measured in triplicate for sample solution over a temperature range (295-331 K)

with random increments. The absorbance of the solutions was evaluated using the Beer–Lambert’s formula;

$$A = -\log(T) \dots\dots\dots 3$$

where A is the absorbance and T is the transmittance. This experiment was carried out in dark room so as to eliminate detection of stray light.

3.0 Results and Discussion

Figure 1 displays curves of absorbance versus concentration of sucrose in aqueous solution monitored at temperatures; 295, 312, 319, and 331 K. From the graphs, it is noted that there was an overall increase in absorbance with concentration. This has been attributed to an increase in number of absorbing sucrose molecules in aqueous solution according to Beer-Lambert’s law;

$$A = \alpha bc \dots\dots\dots 4$$

where A is the absorbance, α is molar absorptivity, b the path length and the concentration.

The rate of absorbance initially at 5% concentration is high and decreases gradually onwards to 40% concentration. This non-linear absorbance feature was ascribed to the particulate chemical dynamics resulting from increased solute-solute interaction. This results into a shift in chemical equilibrium as a function of concentration that consequently causes different charge distribution on their neighboring species in solution. Since ES is an electron phenomenon, the absorptive coefficient was adversely affected due to the electrostatic interaction between molecules in close proximity.

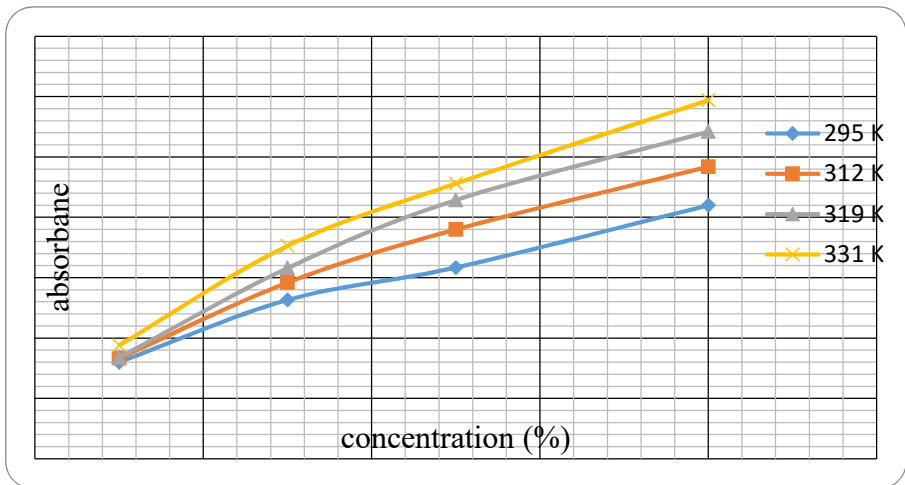


Figure 1. Graphs of absorbance versus concentration of sucrose in aqueous solution at different temperatures

The absorbance feature shifts with temperature for the same concentration. This effect being independent of all external factors; could be due to the thermal motion of the solute molecules in the solution. This may have occurred due to increased mobility at high temperatures. Tinashe (2008) has shown that refractive index η , of sugar solutions reduce with an increase in temperature. This means, an increase in temperature reduces viscosity of the fluid, thus more solute molecules will move much freely in the suspension. Consequently, these sucrose particulates will interfere with the radiation resulting to increased attenuation. This follows directly from Albert Einstein’s law for the mean square displacement of a particle suspended in a fluid (equation 2). According to Jenkins (1976), the intensity of the transmitted radiation will be reduced as a result of attenuation due to both molecular absorption and scattering resulting to more absorbance.

Figure 2 displays graph of absorbance versus temperature for sucrose solutions of different concentrations. There is a linear increase in absorbance as temperature increases.

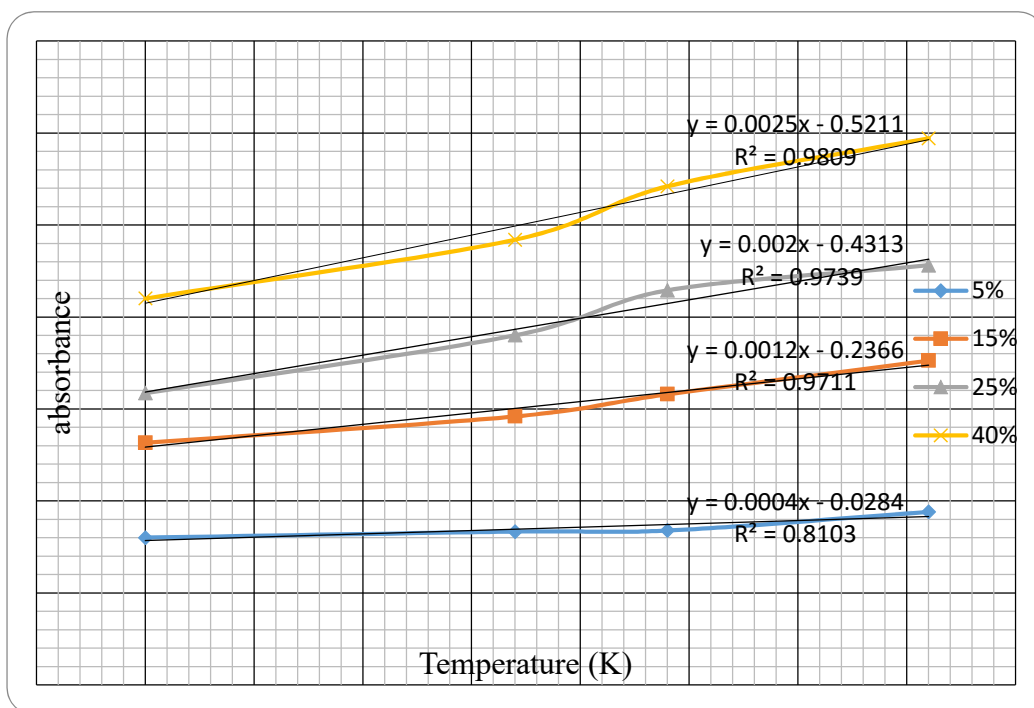


Figure 2: Graphs of absorbance versus temperature for sucrose solution of different concentrations

The temperature of sugar aqueous solutions correlated well with absorbance features with PLS, R2 found to be 0.810, 0.971, 0.973 and 0.980 for 5%, 15%, 25%, and 40% concentrations respectively. This implies that, absorbance is a function of

temperature for a particular concentration. This is shown to occur on the basis of kinetic molecular theory. According to this theory, molecules at a temperature greater than zero possess kinetic energy which results to particulates moving in random motion. In principle, the intensity of the random motion is increased with an increase in temperature. This is shown to follow directly from Albert Einstein's law for the mean kinetic energy of a particle suspended in this ambience (Equation 1). High concentration implies more sucrose solutes in the solution that attenuates the radiation beam per unit time than at low concentrated solution.

4.0 Conclusion

Calibration performance on sugar concentration in aqueous is shown to shift when absorbance feature is collected across a range of temperatures. The temperature of sugar solution correlated well with absorbance features with PLS, R2 found to be 0.810, 0.971, 0.973 and 0.980 for 5%, 15%, 25% and 40% concentrations respectively. This shift in absorbance feature was attributed to the physical principle of Brownian motion with reference to kinetic molecular theory.

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