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Contribution on Determination of the Rate Constant of Sucrose Hydrolysis in 20, 24 and 28°C in H_2O and CH_3OH Mixture and the Order of Reaction

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Abstract: For studying the hydrolysis of sucrose there is different methods. The angle of rotation can be determined by polarimetry. Then we can obtain the constant of rate of reaction, k. In this study, the hydrolysis of sucrose 1/20 M was investigated by using HCl as catalyst and in presence and absence of methanol in 20, 24 and 28°C. This investigation was performed by polarimetry method. Obtained results show that the plot of $ln(\alpha_o - \alpha_\infty)/(\alpha_t - \alpha_\infty)$ against time (second) is linear which can be attributed to a first order reaction. The constant of rate of hydrolysis increases with temperature increasing. The angle of rotation and constant of rate of sucrose hydrolysis in presence of methanol is smaller than in its absence.
Keywords: sucrose, hydrolysis, constant of rate, first order, polarimetry, angle of rotation.

Introduction

There are different methods for determination of constant of rate and order of a reaction [1, 2], one of this methods is determining the angle of rotation, α. In this paper, we have determined the angle of rotation of hydrolysis of sucrose in presence and absence of methanol and effect of temperature on it, by polarimetry. Sucrose rotates polarized light to right- hand (Dextrorotary), glucose rotates also, polarized light to right- hand. But fructose rotates polarized light to left- hand (Levorotary). Experimental results show that equimolecular mixture of glucose and fructose rotates polarized light to left- hand [3, 4, 5]. Considering α_o and α_∞ as rotation angle of solution at t = 0 and at the end of hydrolysis respectively, and α_1 as rotation angle at t time, using these rotation angles and kinetic's general low, we can obtain the value of rate constant [6, 7, 8].

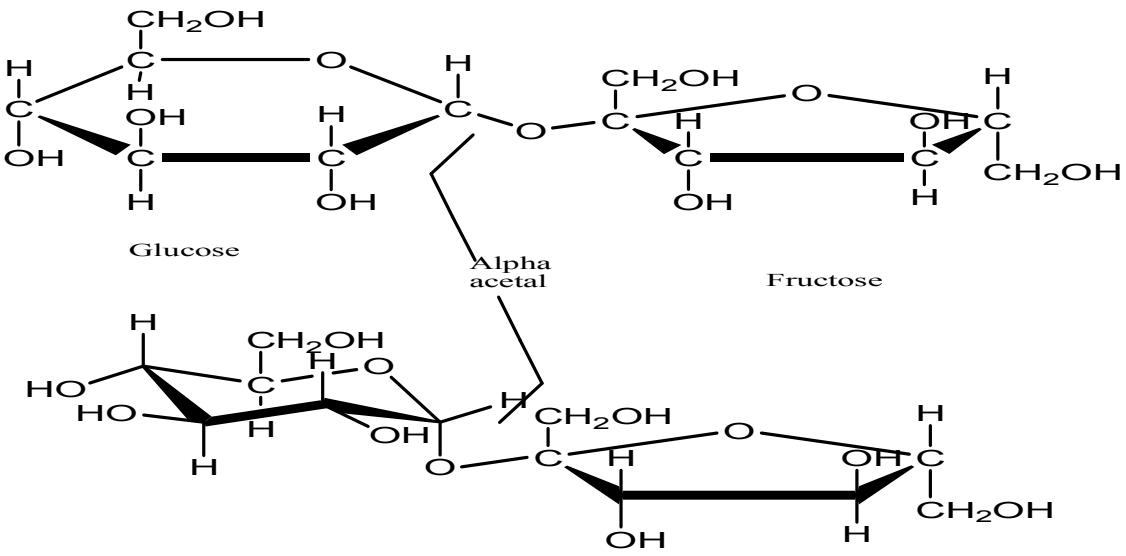


Figure 1. A scheme of sucrose dissociation to glucose and sucrose

Materials and Methods

Instrument. POLAX-2L polarimeter was used for polarimetry experiments.

Method. Polarimetry was performed on sucrose 1/20 M, and HCl 1/20 M. Total volume of the cell is 10 $cm^3$and the pathway of polarized light is 10 cm.

Hydrolysis data. All experiments were performed at 20, 24, and 28 Celsius degree. Polarimeter was set at determined temperature. We have put 5 cm^3 of sucrose 1/20 M and 5 cm^3 of HCl 1/20 M into the cell, and we wait while temperature of cell set with polarimeter's one. Then we have determined α_o, α_t and α_∞, at 20, 24, and 28^oC. The obtained results by using HCl as catalyst in presence and absence of methanol were shown in tables 1 to 6. The constant of rate of hydrolysis must be constant in constant concentration and temperature. But the tables 1 to 6 show that k is not constant. This may be interpreted as following: because time and temperature are not constant, there will be experimental errors. Therefore the averages were calculated.

Results and Discussion

The plots shown in figures 1 to 6 show the variation of $ln\frac{\alpha_\circ - \alpha_\infty}{\alpha_t - \alpha_\circ}$ against time (second) in absence and in presence of methanol, and in 20, 24, and 28 degree of Celsius, respectively. Based on the equation $kt = ln\frac{\alpha_\circ - \alpha_\infty}{\alpha_t - \alpha_\infty}$ and linearity of plots, the results deducted show that hydrolysis of sucrose in presence of hydrochloric acid as catalyst, and in absence and presence of methanol is a first order reaction. The figures 7 and 8 show the variation of constant of rate (k) against temperature (^oC), in absence and presence of methanol, respectively. The plots show that k increase with temperature increasing.

Conclusion

Based on experimental results, it may be concluded that the linearity of plots show the kinetic of first order for hydrolysis reaction. The constant of rate, also, increase with temperature increasing (figures 7 and 8).

Table 1- Angle of rotation and k for hydrolysis of sucrose at 20°C and in absence of methanol

Time s	α	$ln\frac{\alpha_\circ-\alpha_\infty}{\alpha_t-\alpha_\circ}$	k s^{-1}
0	1.10	-	-
180	0.75	0.362	2.016×10^{-3}
360	0.65	0.496	1.387×10^{-3}
540	0.55	0.650	1.204×10^{-3}
720	0.45	0.832	1.156×10^{-3}
930	0.35	1.056	1.135×10^{-3}
∞	-0.05	-	-
average			1.377×10^{-3}

Table 2- Angle of rotation and k for of of hydrolysis of sucrose at 20°C and in presence of methanol

Time s	α	$ln\frac{\alpha_\circ-\alpha_\infty}{\alpha_t-\alpha_\circ}$	k s^{-1}
0	0.85	-	-
150	0.65	0.251	1.675×10^{-3}
360	0.50	0.492	1.367×10^{-3}
650	0.40	0.693	1.066×10^{-3}
900	0.30	0.944	1.049×10^{-3}
1260	0.20	1.280	1.016×10^{-3}
1750	0.10	1.791	1.023×10^{-3}
∞	-0.05	-	-
average			1.199×10^{-3}

Table 3. Angle of rotation and k for hydrolysis of sucrose at 24°C and in absence of methanol

Time s	α	$ln\frac{\alpha_\circ-\alpha_\infty}{\alpha_t-\alpha_\circ}$	k s^{-1}
0	1.40	-	-
110	1.10	0.231	2.100×10^{-3}
220	0.90	0.422	1.922×10^{-3}
370	0.70	0.659	1.781×10^{-3}
600	0.50	0.969	1.615×10^{-3}
800	0.40	1.170	1.462×10^{-3}
∞	-0.05	-	-
average			1.776×10^{-3}

Table 4. Angle of rotation and k for hydrolysis of sucrose at 24°C and in presence of methanol

Time s	α	$ln\frac{\alpha_\circ-\alpha_\infty}{\alpha_t-\alpha_\circ}$	k s^{-1}
0	0.85	-	-
100	0.65	0.182	1.820×10^{-3}
230	0.50	0.405	1.760×10^{-3}
400	0.40	0.693	1.732×10^{-3}
620	0.30	0.875	1.411×10^{-3}
900	0.20	1.098	1.220×10^{-3}
1200	0.10	1.386	1.155×10^{-3}
∞	-0.05	-	-
average			1.199×10^{-3}

Table 5. Angle of rotation and k for hydrolysis of sucrose at 28°C and in absence of methanol

Time s	α	$ln\frac{\alpha_\circ-\alpha_\infty}{\alpha_t-\alpha_\circ}$	k s^{-1}
0	1.65	-	-
60	1.40	0.159	2.651×10^{-3}
130	1.20	0.307	2.365×10^{-3}
200	1.05	0.435	2.176×10^{-3}
280	0.90	0.581	2.078×10^{-3}
430	0.70	1.818	1.903×10^{-3}
∞	-0.05	-	-
average			2.234×10^{-3}

Table 6. Angle of rotation and k for hydrolysis of sucrose at 28°C and in presence of methanol

Time s	α	$ln\frac{\alpha_\circ-\alpha_\infty}{\alpha_t-\alpha_\circ}$	k s^{-1}
0	1.45	-	-
80	1.20	0.182	2.279×10^{-3}
170	1.00	0.356	2.094×10^{-3}
300	0.80	0.567	1.893×10^{-3}
420	0.60	0.762	1.814×10^{-3}
560	0.50	1.003	1.791×10^{-3}
750	0.35	1.321	1.761×10^{-3}
∞	-0.05	-	-
average			1.938×10^{-3}

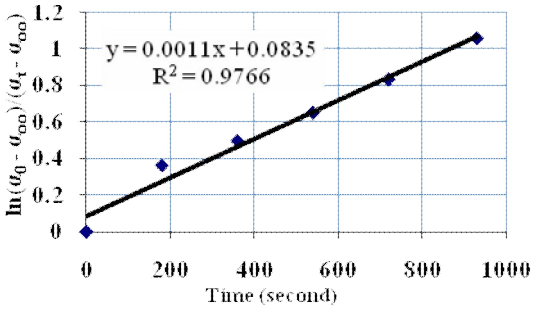


Figure 1. Variation of $ln\frac{\alpha_\circ - \alpha_\infty}{\alpha_t - \alpha_\circ}$ against time in 20°C, in absence of methanol

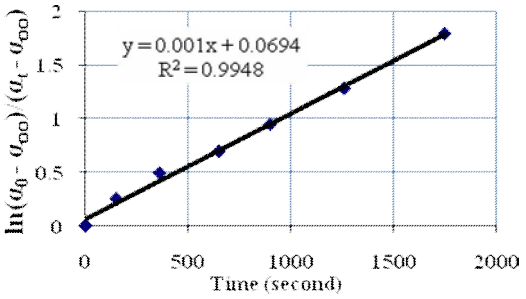


Figure 2. Variation of $ln\frac{\alpha_\circ - \alpha_\infty}{\alpha_t - \alpha_\circ}$ against time in 20°C, in presence of methanol

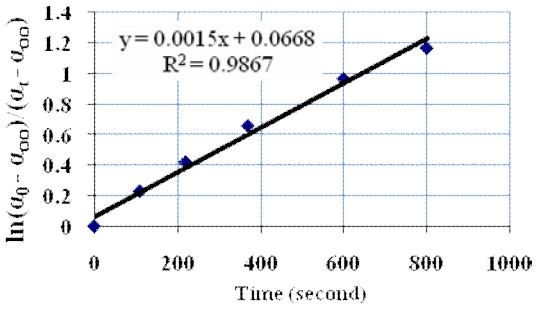


Figure 3. Variation of $ln\frac{\alpha_\circ - \alpha_\infty}{\alpha_t - \alpha_\circ}$ against time in 24°C, in absence of methanol

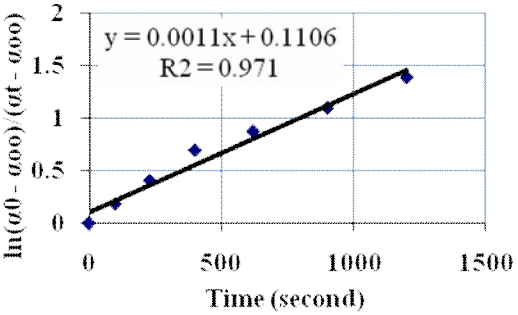


Figure 4. Variation of $ln\frac{\alpha_\circ - \alpha_\infty}{\alpha_t - \alpha_\circ}$ against time in 24°C, in presence of methanol

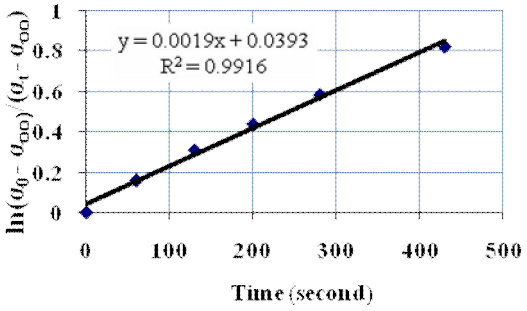


Figure 5. Variation of $ln\frac{\alpha_\circ - \alpha_\infty}{\alpha_t - \alpha_\circ}$ against time in 28°C, in absence of methanol

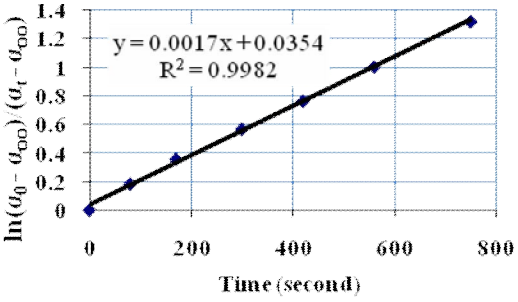


Figure 6. Variation of $ln\frac{\alpha_\circ - \alpha_\infty}{\alpha_t - \alpha_\circ}$ against time in 28°C, in presence of methanol

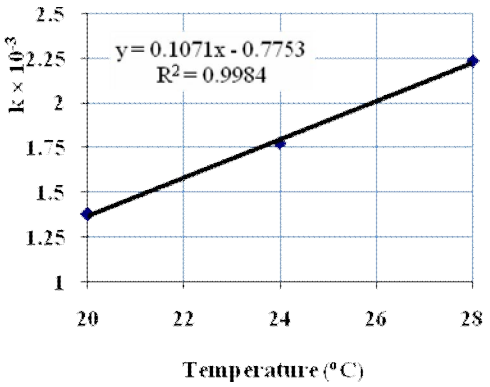


Figure 7. Variation of k with t (^{o}C) in absence of methanol

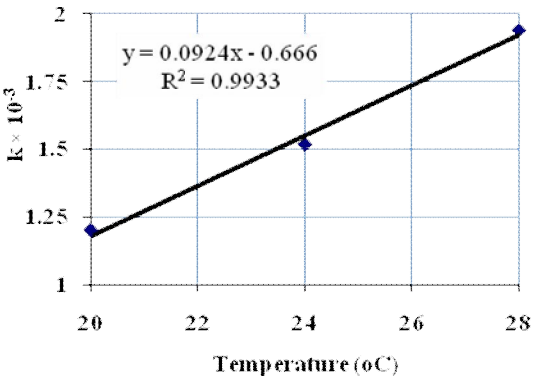
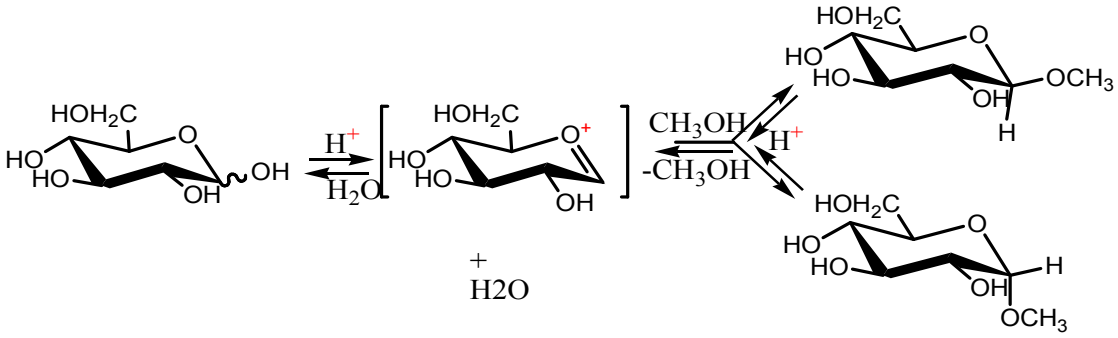


Figure 8. Variation of k with t (^{o}C) in presence of methanol

The results deduced from plots show that the angle of rotation and the constant of rate of sucrose hydrolysis in presence of methanol are smaller than the constant of rate of sucrose hydrolysis in absence of methanol. This phenomenon may be interpreted as following: sucrose transform to glucose and fructose by hydrolysis as shown in formula 1.

$$C_{12}H_{22}O_{11} + H_2O \rightarrow C_6H_{12}O_6\,(glucose) + C_6H_{12}O_6\,(fructose) \quad (1)$$

When methanol was added to sucrose solution, glucose which has hemiacetal, will form acetal. Mechanism of reaction may be as following:



Above mechanism show that methanol addition form β – glucoside which form a new chiral center and affect on angle of rotation. In fact each compound which has a chiral center has its proper angle of rotation [1, 2]. Therefore, the value of constant of rate decrease with decrease of angle of rotation in accordance with $k = \frac{1}{t} ln \frac{\alpha_\circ - \alpha_\infty}{\alpha_t - \alpha_\infty}$ relation.

Decrease of constant of rate with methanol addition, also, may be attributed to the fact that methanol addition to sucrose increases the activation energy. Moreover, there is a relation between activation energy and activation enthalpy $(E_a = \Delta H + RT)$, and activation enthalpy depends also to activation Gibbs energy $(\Delta G = \Delta H - T\Delta S)$ [9, 10, 11].

Thus increase in activation energy increase activation Gibbs energy and decrease K ($K = e^{\frac{-\Delta G}{RT}}$). This means that, increase in activation enthalpy decrease constant of rate, k. Thus, as sucrose hydrolysis, the addition of methanol decreases angle of rotation and constant of rate.

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