




High-Resolution Determination of Kinetic Parameters of Sucrose Hydrolysis Based on Weak Measurement

Peng Tang , Yetao Shu, Zhaoxin Wen, Yifei Song, Shuoqing Liu , Ting Wan, and Zhaoming Luo 

Abstract—We propose a high-resolution scheme for determining the kinetic parameters of sucrose hydrolysis based on the weak measurement, and the parameters including rate constant, half-life, activation energy and pre-exponential factor are experimentally determined. In the scheme, the postselection state of weak measurement is modified by the optical rotation angle in the process of sucrose hydrolysis, and the amplified spin-Hall shift acts as a probe for determining the kinetic parameters. The rate constant and half-life are obtained based on the time variations of amplified spin-Hall shifts under different reaction conditions of temperatures and hydrochloric acid concentrations. The corresponding activation energy and pre-exponential factor are also evaluated for explaining the physical mechanism which influences the rate constant and analyzing how to adjust the reaction conditions to predict or control the rate. The high resolution for optical rotation angle is achieved in our scheme, which can reach 4.9×10^{-4} degree with one order of magnitude improvement over the polarimeter. These results can provide a possibility for the determination of chemical kinetic parameters with high-precision, real-time, label-free and convenient effects.

Index Terms—Weak measurement, Spin-Hall shift, Kinetic parameter.

I. INTRODUCTION

THE determination of chemical kinetic parameters, including rate constant, half-life, activation energy and pre-exponential factor, can provide valid data for revealing the chemical mechanism, and then help to control reaction conditions and improve the efficiency of actual industrial production [1], [2].

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The current studies on the determination of kinetic parameters usually take sucrose hydrolysis as an example, which can be easily extended to other chemical reactions [3]. Generally, the kinetic parameters of sucrose hydrolysis are determined by monitoring the optical rotation angle using a polarimeter, with the apparent advantages of real-time and label-free [4]. But the polarimeter requires cumbersome adjustment of polarizers and wave plates during the monitoring process, and its measurement accuracy of the optical rotation angle is less than 10^{-3} degree [5], [6]. In order to solve the problem of low measurement accuracy, some methods, such as liquid chromatograph, magnetic resonance imager and Raman spectrometer, have been reported for the determination of kinetic parameters [7]–[10]. Nonetheless, these methods have some disadvantages in the process of measurement, such as destroying the reaction process and being unable to monitor in real time. Therefore, it is urgent to explore a high-precision, real-time, label-free and convenient method for the determination of chemical kinetic parameters.

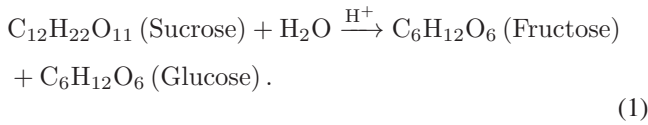
The weak measurement theory was first proposed by Aharonov *et al.* in 1988 [11]. By introducing approximately orthogonal preselection state and postselection state, and maintaining a small interaction intensity, we can obtain the value that is several times larger than the eigenvalue [12]. Hosten *et al.* experimentally observed the spin-Hall shift via the weak measurement in 2008 for the first time [13], [14], which was further explained as the result of the significant destructive interferences between a spin-flipped abnormal mode acquiring geometric phases and a spin-maintained normal mode without such phases [15]. The weak measurement system also has the benefits of real-time, label-free, low-cost and convenience, etc [16], [17]. Specially, the spin-Hall shift has a sensitive dependence on structural parameters [18], [19], thus the weak measurement with the combination of the spin-Hall shift can be used as a high-resolution measure tool of structural parameters, such as the number of graphene layers and the thickness of nano film [20]–[24]. Recently, the weak measurement has also been applied in the field of biosensing [25]–[30]. In 2011, Marcel Pfeifer and Peer Fischer discussed how the weak measurement can be used to measure the optical activity [31]. Qiu *et al.* demonstrated that the weak measurement combined with spin-Hall shift could be applied in the determination for the optical rotation of chiral molecules [32]. Subsequently, some researchers utilized the weak measurement to determine the concentration of metal ions and chiral compounds by monitoring the optical rotation angle [33]–[35]. Since the optical rotation angle can change in the chemical reactions process, we believe that the weak

measurement has the potential to be applied to determine precisely kinetic parameters by monitoring the spin-Hall shift.

In this paper, we offer a high-resolution determination proposal for the kinetic parameters of sucrose hydrolysis based on the weak measurement, and experimentally determine the parameters, consisting of rate constant, half-life, activation energy and pre-exponential factor. First, we establish a quantitative relationship between the amplified spin-Hall shift and the optical rotation angle in the process of sucrose hydrolysis. Then, we monitor the time variations of amplified spin-Hall shifts at different temperatures and catalyst concentrations. Finally, we can obtain the corresponding kinetic parameters of sucrose hydrolysis.

II. THEORETICAL ANALYSIS

The basic task of chemical kinetics is to study the influence of reaction conditions on the rate and reveal its mechanism, thereby being helpful to optimize the actual industrial production. Remarkably, the study of chemical kinetics is mainly achieved by determining kinetic parameters, comprising rate constant k , half-life $t_{1/2}$, activation energy E_a and pre-exponential factor A . The reaction formula of sucrose hydrolysis can be described as [36], [37]



Under the catalysis of hydrogen ions (H^+), the sucrose ($C_{12}H_{22}O_{11}$) and water (H_2O) react to form the fructose ($C_6H_{12}O_6$) and glucose ($C_6H_{12}O_6$). However, the water is present in great excess, and the consumption of water used in the reaction is negligible. The sucrose hydrolysis can be regarded as the first-order reaction, and the kinetic equation is given by [36]

$$\ln C_t = -kt + \ln C_0, \quad (2)$$

where C_0 and C_t are respectively the initial sucrose concentration ($t = 0$) and the sucrose concentration at any time t , and k denotes rate constant. The constant k is an important indicator to describe the chemical reaction rate and assess the reaction ability. Actually, the optical rotation angle in sucrose hydrolysis process is closely related to the concentration of the sucrose, and the optical rotation angle at any time α_t can be expression as

$$\alpha_t = K_r C_t + K_p (C_0 - C_t), \quad (3)$$

where K_r and K_p are the proportional constants of reactant and of product, respectively. By analyzing 3, we can obtain that the initial optical rotation angle and the final optical rotation angle are respectively $\alpha_0 = K_r C_0$ and $\alpha_\infty = K_p C_0$, and both of them are constant value. By substituting 3 into 2, the kinetic equation can be rewritten as [37]

$$\ln (\alpha_t - \alpha_\infty) = -kt + \ln (\alpha_0 - \alpha_\infty). \quad (4)$$

We note that, in 4, the relationship of $\ln (\alpha_t - \alpha_\infty)$ versus t is linear, and the negative value of its slope is the rate constant k . The half-life $t_{1/2}$ describes chemical reaction rate from the time dimension, and can be defined as the time taken for the reactant concentration to reach half of its initial value (i.e. $C_t = C_0/2$).

By the way, the expression can also be represented as $\alpha_t = (\alpha_0 + \alpha_\infty)/2$ according to 3. $C_t = C_0/2$ can be substituted into 2 and $\alpha_t = (\alpha_0 + \alpha_\infty)/2$ into 4, and these two ways can obtain the half-life $t_{1/2}$, which can be expressed as

$$t_{1/2} = \frac{\ln 2}{k}. \quad (5)$$

The $t_{1/2}$ can be used to calculate and predict the time at different conversion rates for reactant. The chemical reaction rate is usually influenced by different reaction conditions of catalyst, temperature and pressure, and their influence mechanism can be explained by collision theory [38]. The theory explains the essence of chemical reactions from a microscopic view, and states that chemical reaction only occurs by generating effective collisions among activated molecules which is usually converted from ordinary molecules, requiring the minimum convert energy called activation energy E_a . The frequency of effective collision among activated molecules is called pre-exponential factor A , which is also regarded as the limit value of the rate constant at high temperature. It is noted that these kinetic parameters are not mutually isolated, and the relationship between them can be expressed by Arrhenius formula [39]

$$\ln k = -\frac{E_a}{RT} + \ln A, \quad (6)$$

where T is the kelvin temperature and R represents the Molar gas constant. From the equation, we can learn that the plot of $\ln k$ versus $1/T$ is a straight line, and its slope and intercept are closely associated with activation energy E_a and pre-exponential factor A . In practical production, the E_a and A are mainly influenced by the catalyst, and the change of reaction rate can be achieved by adjusting the catalyst concentration. The rising temperature and pressure usually increase the percentage of activated molecules, resulting in a rise of reaction rate. Based on the above analyses, we can summarize that the reaction rate can be predicted and controlled by altering the reaction conditions.

In the previous weak measurement setup, the refractive index change of the sample is sensed by measuring the spin-Hall shift between the sample and the substrate [40], [41]. The setup of directly measuring the spin-Hall shift after the beam passing through the sample is difficult to apply to determinate the kinetic parameters of sucrose hydrolysis, owing to the ambiguous relationship between the refractive index and the kinetic parameters. It is well known to us that the kinetic parameters are usually determined by monitoring the optical rotation angle [35], thus we adjust the position of sample to establish a weak measurement setup for the determination of the kinetic parameters, as shown in Fig. 1. First, a Gaussian beam with wavelength $\lambda = 632.8$ nm generated by a He-Ne laser passes through a lens (Lens1) to produce a focused beam. Here, the half-wave plate (HWP) is applied to adjust the light intensity. The focused beam is selected as a horizontal polarization via the Glan polarizer (GLP1), and the preselection state $|\psi_i\rangle$ is obtained as

$$|\psi_i\rangle = |H\rangle = \frac{1}{\sqrt{2}} (|+\rangle + |-\rangle), \quad (7)$$

where $|+\rangle$ and $|-\rangle$ represent respectively the left- and right-circular polarization states. Then, the light beam impinges onto

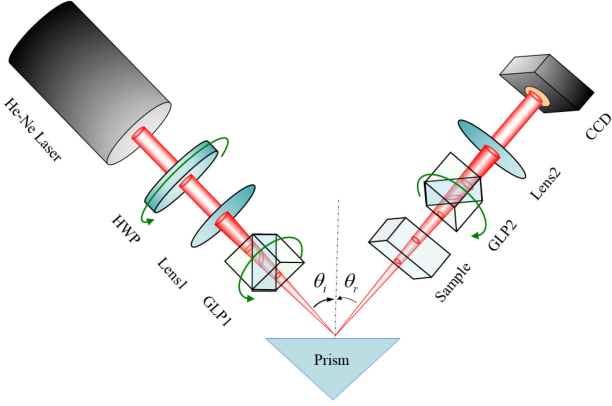


Fig. 1. The schematic of experimental setup for weak measurement. GLP1 and GLP2, Glan polarizer; HWP, half-wave plate; Lens1 and Lens2, lenses with effective focal length of 50 mm and 250 mm, respectively; Prism, BK7 glass; CCD, charge-coupled device; Sample, sucrose hydrolysis. The light source is a 21 mW linearly polarized He-Ne laser at 632.8 nm (Lumentum 1145P). The length of the Sample is chosen as $l = 1$ cm.

the air-prism interface, and the spin-Hall shift is induced which can be written as [13]

$$\delta = \frac{(r_p + r_s) \cot \theta_i}{k_0 r_p}, \quad (8)$$

where θ_i is the incident angle, k_0 indicates the wave vector of vacuum, r_s and r_p represent the Fresnel coefficients at air-prism interface for parallel and perpendicular polarizations, respectively. Next, the light beam passes through the sucrose hydrolysis sample and the Glan polarizer (GLP2). Markedly, GLP2 and GLP1 must be completely orthogonal in the experimental setup, so that the polarization of the light beam is only modified by the optical rotation angle α in the process of sucrose hydrolysis. Thus, the postselected angle is α in the experimental setup, instead of the small offset angle between the vertical direction of GLP1 and GLP2 in the previous weak measurement system. The optical rotation angle α can be expressed as [3]

$$\alpha = l \cdot c \cdot [\alpha_\lambda^T]. \quad (9)$$

Here, c and l are the concentration of sample solution and the length of sample. $[\alpha_\lambda^T]$ is the specific rotation which is influenced by temperature and wavelength [42], [43], and the maximum specific rotation in the sucrose hydrolysis process $[\alpha_\lambda^T]_{\max} \approx 66.4^\circ$ with $\lambda = 632.8$ nm at room temperature. The postselection state $|\psi_f\rangle$ is introduced by sucrose hydrolysis sample and GLP2, which is described as

$$|\psi_f\rangle = |V + \alpha\rangle = \frac{i}{\sqrt{2}} (e^{+i\alpha} |-\rangle - e^{-i\alpha} |+\rangle). \quad (10)$$

By incorporating the weak-value amplification, the initial spin-Hall shift is enhanced. The weak value A_w can be defined as [33]

$$A_w = \frac{\langle \psi_f | \sigma_3 | \psi_i \rangle}{\langle \psi_f | \psi_i \rangle}. \quad (11)$$

Here, σ_3 indicates the Pauli operator. Finally, the beam is collimated through Lens (Lens2) which form optical confocal

cavities with the combination of Lens1. Here, the propagation amplification F is introduced, which can be described as

$$F = \frac{4\pi \langle y_{L2}^2 \rangle}{(z_{eff} \lambda)}. \quad (12)$$

Here, $\langle y_{L2}^2 \rangle$ is the y-direction transverse distribution after the light beam passes Lens2, and z_{eff} is the effective focal length of Lens2. After weak-value amplification and propagation amplification, the amplified spin-Hall shift δ_{Aw} is recorded by the CCD (Coherent Lasercam HR) and written as [17]

$$\begin{aligned} \delta_{Aw} &= \pm F |A_w| \delta \\ &= \pm \frac{z[r_p(r_p + r_s)] \sin(2\alpha) \cot \theta_i}{(r_p + r_s)^2 \cot^2 \theta_i \cot^2 \alpha + 2k_0 r_p^2 z_r \sin^2 \alpha}, \end{aligned} \quad (13)$$

here, z_r is the Rayleigh distance and z denotes the propagation distance associated with Lens2. According to 13, we can know the amplified spin-Hall shift is closely related to the optical rotation angle and the incident angle. When the incident angle is fixed, we can use the amplified spin-Hall shift as a probe to monitor the optical rotation angle. By combining Eqs. (1)–(6), we can further evaluate the corresponding kinetic parameters.

III. RESULTS AND DISCUSSION

In this section, we will take the amplified spin-Hall shift as a probe to determine the kinetic parameters of sucrose hydrolysis based on the experimental setup, as shown in Fig. 1. The sample parameters are as follows: the concentration of sucrose $c = 0.04$ g/ml, the length of sample $l = 1$ cm. It is known that the kinetic parameters of sucrose hydrolysis are influenced by many reaction conditions, such as temperature, catalyst and pressure. In the following discussion, we mainly focus on the influence of temperature and catalyst. To determine the kinetic parameters, we need to establish a quantitative relationship between the amplified spin-Hall shift and the optical rotation angle in the process of sucrose hydrolysis. Subsequently, we can further infer the time variations of optical rotation angles by monitoring the time variations of amplified spin-Hall shifts in the process of sucrose hydrolysis at different temperatures and catalyst concentrations. Based on the formula of kinetic parameters regarding optical rotation angle, we will obtain rate constant k , half-life $t_{1/2}$, activation energy E_a and pre-exponential factor A .

First, we establish a quantitative relationship between the amplified spin-Hall shifts and the optical rotation angles in the process of sucrose hydrolysis. By using 9, we can infer the maximum optical rotation angle $|\alpha_{\max}| = l \cdot c \cdot [\alpha_\lambda^T]_{\max} \approx 0.266^\circ$ in the sucrose hydrolysis process according to the sample parameters $c = 0.04$ g/ml and $l = 1$ cm. Thus, we reckon that the optical rotation angle α in the sucrose hydrolysis process ranges from -0.28° to 0.28° in the following discussion. And then we study the relationship between amplified spin-Hall shifts and the optical rotation angles in the narrow optical rotation angle range, and theoretically simulate the relationship at the certain incident angle $\theta_i = 50^\circ$ via 13 [see solid line in Fig. 2]. To verify this theoretical result, we imitate the optical rotation angle in the process of sucrose hydrolysis by adjusting the

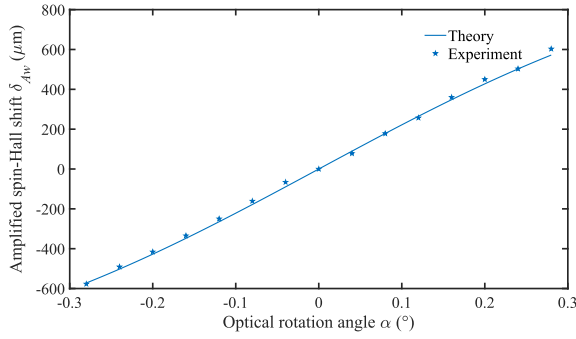


Fig. 2. The relationship of amplified spin-Hall shift and the optical rotation angle at the incident angle $\theta_i = 50^\circ$. The solid line and pentacle dotted line are theoretical results and experimental values, respectively.

included angle between GLP2 and GLP1, and experimentally determine the amplified spin-Hall shifts varying with the optical rotation angles [see pentacle dotted line in Fig. 2]. Compared with the theoretical result and the experimental values in Fig. 2, it can be found that the experimental values are consistent with the theoretical result and both of them have good linearity. When the optical rotation angle changes from -0.28° to 0.28° , the amplified spin-Hall shift increases linearly by $1144 \mu\text{m}$. Therefore, in our experimental setup, the resolution for optical rotation angle can reach 4.9×10^{-4} degree since the resolution of CCD for observing the amplified spin-Hall shift is $1 \mu\text{m}$.

Then, we monitor the time variations of amplified spin-Hall shifts under different reaction conditions of temperatures and catalyst concentrations in the process of sucrose hydrolysis. Usually, the sucrose hydrolysis is catalyzed by hydrochloric acid (HCL) [4]. In subsequent work, the HCL concentrations are chosen as 2.0 mol/L, 2.5 mol/L, 3.0 mol/L, 3.5 mol/L and 4.0 mol/L, which accordingly correspond to the cross dotted line, square dotted line, triangle dotted line, pentagram dotted line and circular dotted line in the following figures. For facilitating the monitoring of sucrose hydrolysis, we record data every 5 min at lower temperatures (287.5K and 293.5K) and 3 min at higher temperatures (298.0K) since the reaction rate increases with the rising of temperatures. Here the change of temperature is realized by heating in a water bath. Fig. 3(a) shows that the time variations of amplified spin-Hall shifts (i.e the relationship between δ_{Aw} and t) in sucrose hydrolysis catalyzed by different HCL concentrations at 287.5K. It is shown that the amplified spin-Hall shifts hardly change with time in pure water [see the diamond dotted line in Fig. 3(a)], but decrease with the increase of time when HCL is added. Moreover, the amplified spin-Hall shifts at a certain time decrease with increasing HCL concentration. To investigate the influence of temperature on sucrose hydrolysis, we also monitor the time variations of corresponding amplified spin-Hall shifts at 293.5 K and 298.0 K. Compared with Figs. 3(a)–3(c), it is found that the amplified spin-Hall shifts at certain time decrease with the increasing of temperature at the same HCL concentration.

Finally, we obtain the kinetic parameters of sucrose hydrolysis under different reaction conditions of temperatures and HCL concentrations. As the amplified spin-Hall shifts linearly vary

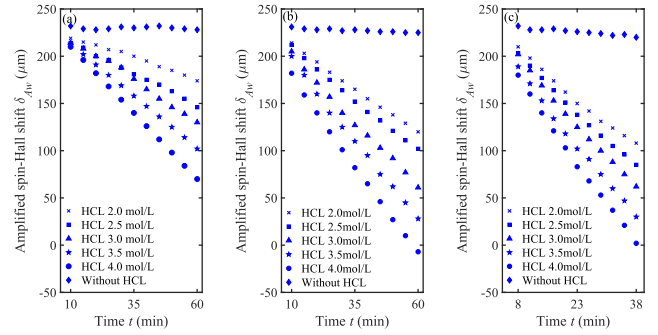


Fig. 3. The time variations of the amplified spin-Hall shifts in sucrose hydrolysis catalyzed by different HCL concentrations at temperatures T of (a) 287.5K, (b) 293.5K, and (c) 298.0K. The cross dotted line, square dotted line, triangle dotted line, pentagram dotted line and circular dotted line correspond to the HCL concentrations of 2.0 mol/L, 2.5 mol/L, 3.0 mol/L, 3.5 mol/L, and 4.0 mol/L. The diamond dotted line represents the absence of HCL.

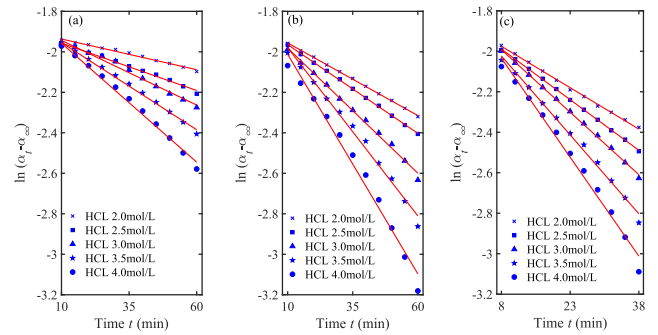


Fig. 4. The relationship of $\ln(\alpha_t - \alpha_\infty)$ versus t for sucrose hydrolysis catalyzed by different HCL concentrations at different temperatures T of (a) 287.5K, (b) 293.5K, and (c) 298.5K. The line type of experimental data at different HCL concentrations is the same as that in Fig. 3. The red solid lines are the results of fitting the experimental data.

with the optical rotation angles in Fig. 2, we can infer the time variations of optical rotation angles (i.e the variation of α_t with t) based on the relationship between δ_{Aw} and t in Fig. 3, and then obtain the relationship of $\ln(\alpha_t - \alpha_\infty)$ versus t , as shown in Fig. 4. Here α_∞ is the final optical rotation angle of sucrose solution obtained by heating in water bath at 333 K for 60 min [38]. From Fig. 4, we can see that the relationship of $\ln(\alpha_t - \alpha_\infty)$ versus t is an approximately straight line, which accords with 4. We can also find that the slope of $\ln(\alpha_t - \alpha_\infty)$ versus t is closely related to the rate constant k from 4, and we fit linearly the experimental data. Comparing with Figs. 4(a)–4(c), we can further obtain that k is growing accordingly with the increase of temperature and HCL concentration. In order to describe better the temperature dependence of kinetic parameters, we also monitor the sucrose hydrolysis catalyzed by different HCL concentrations at 288.5K, 290.5K, 292.5K and 295.5K. Here we fit the kinetic parameters for visual comparison. Fig. 5(a) is the temperature dependence of the rate constant k at different HCL concentrations. It is observed that k increases with the temperature and the HCL concentration going up, namely, k is positively correlated with the temperature and the HCL concentration. Fig. 5(b) is corresponding temperature dependence of the

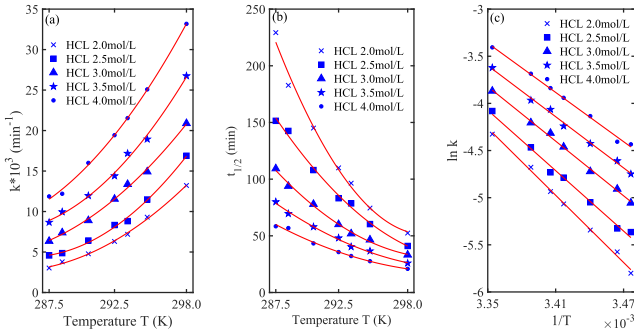


Fig. 5. The temperature dependence of kinetic parameters at different HCL concentrations. (a) The relationship of rate constant k versus T . (b) The relationship of half-life $t_{1/2}$ versus T . (c) The relationship of $\ln k$ versus $1/T$. The line type of experimental data at different HCL concentrations is the same as that in Fig. 3. The red solid lines are the results of fitting the experimental data.

half-life $t_{1/2} = \ln 2/k$ at different HCL concentrations. We can see that $t_{1/2}$ is negatively correlated with the temperature and the HCL concentration. Compared with k , the $t_{1/2}$ characterizes the hydrolysis rate of sucrose from the time dimension, which can help to predict the reaction time for sucrose hydrolysis at different conversion rates. For example, judging from Fig. 5(b), we find that $t_{1/2}$ of sucrose hydrolysis is 229 min at the temperature of 287.5K and the HCL concentration of 2.0 mol/L, then $t_{1/4}$ (i.e. the conversion rate of 75%) can be inferred to be 458 min. Besides the kinetic parameters of rate constant k and half-life $t_{1/2}$, the activation energy E_a and pre-exponential factor A can be evaluated by the slope and intercept of $\ln k$ versus $1/T$. Fig. 5(c) is the relationship of $\ln k$ versus $1/T$ obtained from Fig. 5(a). It can be found that $\ln k$ has a linear relationship with $1/T$, thus we fit linearly the experimental data. From the slope of $\ln k$ versus $1/T$, we can obtain that E_a of the sucrose hydrolysis respectively are 69.35 KJ/mol, 72.32 KJ/mol, 77.82 KJ/mol, 87.30 KJ/mol and 98.68 KJ/mol corresponding to the HCL concentration of 2.0 mol/L, 2.5 mol/L, 3.0 mol/L, 3.5 mol/L and 4.0 mol/L, whose tendency can be summarized that the activation energy E_a of sucrose hydrolysis decreases with the increase of HCL concentration, not being influenced by temperature. By using activation energy and collision theory, we can explain the different influence of the temperature and the HCL concentration on the reaction rate. On the one hand, although the energy provided for the reaction does not increase, the activation energy decreases as the HCL concentration increase, which promotes more activated molecules to generate, and then contribute to the enhancement of reaction rate. On the other hand, while the activation energy does not change, the rising temperature also increases the number of activated molecules because the energy provided for the reaction increases, leading to the increasing of the reaction rate. According to the intercept of $\ln k$ versus $1/T$ in Fig. 5(c), the corresponding pre-exponential factor A are acquired as $2.75 \times 10^{15} \text{min}^{-1}$, $5.91 \times 10^{13} \text{min}^{-1}$, $2.51 \times 10^{12} \text{min}^{-1}$, $4.02 \times 10^{11} \text{min}^{-1}$ and $1.62 \times 10^{11} \text{min}^{-1}$, respectively. The pre-exponential factor A represents the limit value of rate constant at extremely high temperature, and we can find that A decreases with the variation of HCL

concentration, without changing with the temperature. Combining with Arrhenius formula, we can obtain the relationship between temperature and rate constant k at different HCL concentration after determining the activation energy E_a and pre-exponential factor A , both of which are linked to the temperature and catalyst. Therefore, we can adjust the reaction conditions of temperatures and HCL concentrations to predict or control the rate.

So far, we have determined the kinetic parameters of sucrose hydrolysis based on the weak measurement. Compared with the polarimeter, the weak measurement has a high resolution for the optical rotation angle that has one order of magnitude improvement, up to 4.9×10^{-4} degree, and it does not require any adjustment of optical components during the determination process once the experimental setup is established.

IV. CONCLUSION

In summary, we have proposed a high-resolution determination scheme for the kinetic parameters of sucrose hydrolysis based on the weak measurement, and the parameters of rate constant, half-life, activation energy and pre-exponential factor have been experimentally determined. In our experimental setup, the optical rotation angle in the process of sucrose hydrolysis serves as the postselected angle, rather than the included angle between two Glan polarizers (GLP1 and GLP2) in the previous weak measurement. First, we theoretically and experimentally demonstrate the quantitative relationship between the amplified spin Hall shift and the optical rotation angle, and find that the relationship is linear within the optical rotation angle range of from -0.28° to 0.28° . Then, we monitor that the time variations of the amplified spin-Hall shifts in the process of sucrose hydrolysis under different reaction conditions of temperatures and catalyst concentrations, and infer the time variations of the optical rotation angles. Finally, combining with the definition of kinetic parameters related to optical rotation angle, we determine rate constant, half-life, activation energy and pre-exponential factor under different reaction conditions. We explain the physical mechanism of the influence of different reactions on the rate constant by using the activation energy, and discuss how to predict or control the rate by further considering pre-exponential factor. Significantly, our scheme has a high resolution for the optical rotation angle with 4.9×10^{-4} degree, which has an order of magnitude improvement over the polarimeter. In addition, the scheme does not need to adjust the optical elements for the determination of kinetic parameters of sucrose hydrolysis, and provides the possibility for realizing high-precision, real-time and convenient determination of chemical kinetic parameters. It is worth mentioning that the scheme can be extended to the determination of chemical kinetic parameters for the chemical reactions of other chiral molecules, and can also be used to analyse how to control reaction conditions and improve the productivity.

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The authors declare no conflicts of interest.

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