



Phosphorus, Sulfur, and Silicon and the Related Elements

ISSN: 1042-6507 (Print) 1563-5325 (Online) Journal homepage: https://www.tandfonline.com/loi/gpss20

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To cite this article: Mahdieh Darijani, Sayyed Mostafa Habibi-Khorassani, Mehdi Shahraki, Reza Heydari, Yaser Shahbakhsh & Mahshid Hossaini (2019): Kinetic analysis of new multi-component reaction for the formation of Z-N-(3-(naphthalene-2-yl)-4-oxothiazolidine-2-ylidene) benzamide, Phosphorus, Sulfur, and Silicon and the Related Elements, DOI: <u>10.1080/10426507.2019.1655421</u>

To link to this article: <u>https://doi.org/10.1080/10426507.2019.1655421</u>



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Published online: 28 Sep 2019.

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Kinetic analysis of new multi-component reaction for the formation of Z-N-(3-(naphthalene-2-yl)-4-oxothiazolidine-2-ylidene) benzamide

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ABSTRACT

A new three-component reaction was studied kinetically among benzoyl isothiocyanate (1), 1naphthylamine (2), and methyl bromoacetate (3) in the presence of triethylamine (4) as a catalyst, to yield Z-N-(3-(naphthalene-2-yl)-4-oxothiazolidine-2-ylidene) benzamide (5). The overall reaction is a combination of two reactions; 1) reaction **a**, between (1) and (2) forming 1-benzoyl-3-(naphthalen-1-yl) thiourea (P₁); 2) reaction **b**, between (P₁), (3) and (4) to form the product (5). The rate of reaction **a**, $(k_{obs}^a = 66.49 \text{ M}^{-1} \text{ min}^{-1})$ was more than the reaction **b** $(k_{obs}^b =$ 2.9 M⁻¹ min⁻¹), in acetonitrile solvent at 25 °C. A mechanism was proposed involving step₁ (k_{obs}^a) , step₂ (k_2) , step₃ (k_3) and step₄ (k_4) . Substituent effects with electron-withdrawing groups on paraposition of benzoyl isothiocyanate (1) increased the rate constants of k_{obs}^a and k_2 . The large negative entropy, ΔS^{\dagger} , values in reactions **a**, and **b** are in agreement with step₁ (k_{obs}^a) and step₂ (k_2) , an associative mechanism with a negative ΔS^{\ddagger} . The sum of these observations proved that the ratedetermining step (RDS) is step₂. It seems that the most important steps in the reaction mechanism are step₁ (k_{obs}^a) and step₂ (k_2) , which strongly control the reaction process. The kinetics and mechanism of these reactions were assessed by UV-vis spectrophotometry.

GRAPHICAL ABSTRACT



Introduction

Thiazole is a five-member ring heterocyclic compound, which contains nitrogen and sulfur atoms at one and three positions of the ring. Considerable interest has been focused on the chemistry of thiazole and its biological activities, when Williams showed that vitamin B1 had a thiazole ring.^[1,2] The thiazole ring with different substitution makes different properties.^[3] These compounds have diver biological properties such as cardiotonic.^[4] antibacterial,^[5] antifungal^[6] analgesic,^[7] anticonvulsant^[8] antiviral,^[9] anti-inflammatory,^[10] anti-HIV,^[11] and anticancer activities.^[12] Avuconazolre, tiazofurin, ritonavir, nitazoxanide, fentiazac and meloxicam are examples drugs with thiazole moiety.^[13] Among the different methods of thiazole synthesis, more attention has been paid to one-pot

multi-component methods. These reactions have advantages including environmentally friendly, green chemistry, atom economy, energy saving and low waste production.^[14–19] A new series of 4-oxothiazolidine-2-ylidene benzamide derivatives have been synthesized by one-pot multi-component reaction among benzoyl isothiocyanate, (1) various amines, (2) methyl bromoacetate (3) and triethylamine (4) one (Scheme 1).^[20] The investigation on kinetics and mechanism of thiazole derivatives, have rarely been carried out, practically. Because of the important role of these compounds in medicinal chemistry, for the first time a kinetic analysis of the following reaction has been undertaken by UV-vis spectrophotometry for the exploration of its kinetics, thermodynamic and mechanistic aspects. Previously, numerous evaluations have been

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ARTICLE HISTORY

Received 12 June 2019 Accepted 9 August 2019

KEYWORDS

Thiazole; kinetics and mechanism; multi-component; UV-vis spectrophotometry technique



Supplemental data for this article is available online at https://doi.org/10.1080/10426507.2019.1655421.



X=H, CI and CH₃

Scheme 1. The reaction between benzoyl isothiocyanate (1), 1-naphthylamine (2) methyl bromoacetate (3) and triethylamine (4) for the generation of thiazole compounds (5).^[20]



X=H, CI,CH₃

Scheme 2. Both the reactions a, and b involving reactants (1), (2) and (P₁), (3) and (4), respectively for the generating products (5).



Figure 1. Absorbance changes versus wavelengths for the reaction **a**, between (1) (10^{-3} M) and, (2) (10^{-3} M) in acetonitrile for the generation of 1-benzoyl-3-(naphthalen-1-yl) thiourea (P₁) at 5 min intervals up to 60 min; the upward arrow represents the direction of the reaction's progress (P₁).

reported on phosphorus ylied,^[21,22] phosphonate esters,^[23] 1,4 or 1,5 diionic compounds and also two-component reaction,^[24-27] three component condensation^[28,29] and one pot four-component cyclocondensation^[30] by the UV-vis spectrophotometry method. A comprehensive review of our research works can be presented regarding the field of previous mentioned reactions.^[31]

According to the synthetic method,^[20] the overall reaction is a combination of both the reactions \mathbf{a} and \mathbf{b} (Scheme 2).

Thus, in this work, the kinetics of both the reactions **a**, and **b**, have been reported; **a**) reaction of benzoyl

isothiocyanate derivatives (1) and 1-naphthylamine (2) for the formation of thioure derivatives $(\mathbf{p_1})$; b) reaction of thioure derivatives $(\mathbf{p_1})$,^[32] methyl bromoacetate (3) and triethylamine (4) for the generating final product (5).

Results and discussion

Section 1

Determining the experimental rate law for the reaction a

In this section, the reaction **a** between benzoyl isothiocyanate (1) and 1-naphthylamine (2) in acetonitrile (reaction **a**, in Scheme 2), was studied kinetically using UV-vis spectrophotometry apparatus, with the same concentration $(10^{-3}$ M) of each reactant. Periodic scanning of the UV-vis spectra of reaction **a**, were recorded in acetonitrile solvent and an increase in the absorbance was observed in the ranges of 350–420 nm (Figure 1). Kinetic measurements were followed spectrophotometrically through the increase in the absorbance with time in 395 nm wavelength at 20°C, because UV-vis spectra of benzoyl isothiocyanate (1), and 1naphthylamine (2) have relatively very low and constant absorbance at this wavelength (Figure 2). There is relatively no disturbance.

The second-order fitting curve (solid line) that exactly fitted on the experimental values (dotted curve, Figure 3) was examined based on kinetic program,^[33] hence the reaction **a**, follows second-order kinetics ($\alpha + \beta = 2$) at 20°C.



Figure 2. The UV spectra of three single components (benzoyl isothiocyanate (10^{-3} M) (1), 1-naphthylamine (10^{-3} M) (2) and 1-benzoyl-3-(naphthalen-1-yl) thiourea (10^{-3} M) (P₁) in acetonitrile which have been recorded in the same chart.



Figure 3. Dependence of absorbance against time in the reaction a between (1) (10^{-3} M) and (2) (10^{-3} M) in 395 nm wavelength, the dotted curve shows the experimental absorbance values, and the solid curve is the second-order fitting curve at 20 °C.

Equation (1) expresses the rate law,

$$Rate = k_{obs}^{a} [1]^{\beta} [2]^{\alpha}$$
(1)

 $\alpha + \beta$ is the overall order of reaction **a**

 k_{obs}^{a} is a overall rate constant for the reaction **a**. Second-order rate constant ($k_{obs}^{a} = 59.89 \text{ M}^{-1} \text{min}^{-1}$, SD = 0.009) for the reaction rate was automatically computed with the software associated by the kinetic program^[33] at 20°C. Also, the kinetics of the reaction with various concentrations of benzoyl isothiocyanate (1) $(10^{-3}, 2 \times 10^{-3}, 3 \times 10^{-3})$ and 4×10^{-3} M) and constant concentration of 1-naphthylamine (2) (10^{-4} M) was studied to determine the values of the partial orders. A typical kinetic curve of the reaction in pseudo-order condition $(10^{-3} \text{ M} (1) \text{ and } \text{ M} (2))$ is presented in Figure 4. The first-order fitting curve indicates that partial order of 1naphthylamine (2) is one ($\alpha = 1$) and $k_{obs} = 0.052 \text{ min}^{-1}$, Figure 4. In this circumstance the rate law can be written as:

$$Rate = k_{obs}^{pse}[2]^{\alpha}$$
(2)

 $\alpha = 1$ and we have:

$$k_{obs}^{pse} = k_{obs}^{a} [1]^{\beta} \rightarrow \ln k_{obs}^{pse} = \ln k_{obs}^{a} + \beta \ln [1] \quad (3)$$

 $k_{obs}^{pse}\,$ is refer to rate constant under pseudo-order condition. Repeated experiments with other various concentrations of compound (1) under pseudo-order condition at 20°C gave the similar spectrum with the relevant first-order rate



Figure 4. The absorbance plot against time in 395 nm for the reaction between benzoyl isothiocyanate (1) (10^{-3} M) , 1-naphthylamine (2) (10^{-4} M) in acetonitrile. The dotted curve exhibits the experimental values, and the solid curve is the first-order fitted curve at 20 °C.

Table 1. Different first-order rate constant $(k_{obs}^{pse}/min^{-1})^{b}$ with various concentration of compound (1) under pseudo-order condition at 20°C for reaction a.

•				
Experiment. No	(1) M	(2) M	k_{obs}^{pse} min ⁻¹	ln [1]
1	1×10^{-3}	10^{-4}	0.05 (0.001) ^a	-6.90776
2	2×10^{-3}	10^{-4}	0.09 (0.0016)	-6.21461
3	$3 imes 10^{-3}$	10^{-4}	0.16 (0.002)	-5.80914
4	4×10^{-3}	10^{-4}	0.21 (0.0013)	-5.52146

^astandard deviation that was automatically computed with the software associated by the kinetic program.[33]

^bis refer to rate constant under pseudo-order condition.



Figure 5. The plot of $\ln k_{obs}^{pse}$ vs. In [1] to determine the partial order β of compound (1).

constant (k_{obs}^{a}) . The first-order rate constants were recorded in Table 1.

According to the Equation (3), by plotting $\ln k_{abs}^{pse}$ versus $\ln[1]$ the partial order (β) of compound (1) can be determined from the slope of Figure 5 ($\beta = 1.02$). The values of ln [1] and k_{obs}^{pse} are tabulated in Table 1. Based on the mentioned experiments, α and β were iden-

tified equal to one, hence experimental the rate law for the reaction a can be expressed:

$$\operatorname{Rate}_{\mathbf{a}} = k^{\boldsymbol{a}}_{obs}[1][2] \tag{4}$$

Therefore, the reaction **a** follows a second-order kinetics.

Effects of solvents and temperature on the reaction a

1

Previous experiment was carried out in the presence of acetonitrile, to examine the effect of the solvent polarity on the reaction rate, the new experiment was followed in the

Table 2. Rate constants (k_{obs}^a M⁻¹min⁻¹) at different temperatures (±0.1) under the same conditions for the reaction **a**, between (1) and (2) (10⁻³ M).

	$\varepsilon^{b}(D)$	20 °C	25 °C	30 °C	35 ° C
Acetonitrile	37.5	59.89±(0.009) ^a	66.49±(0.0012)	81.45±(0.0011)	91.75±(0.001)
Methyl ethyl ketone	18.22	26.94±(0.0012)	29.08±(0.003)	31.17±(0.001)	34.49±(0.002)

^astandard deviation (SD); ^bdielectric constant.



Figure 6. Arrhenius plot ($ln k_{obs}^{a}$ aginst 1/T) according to Equation (5) for the reaction **a**, between reactants (1) and (2) in both solvents.



Figure 7. Eyring plot $(ln k_{obs}^a/T \text{ versus } 1/T)$ according to Equation (6) for the reaction **a**, between **(1)** and **(2)** in the two solvents.

methyl ethyl ketone solvent. The result exhibited that the reaction in low polar solvent (methyl ethyl ketone) proceeds slowly, Table 2. Temperature is an important factor in the reaction rate, and it is necessary to determine the activation parameters. So, the reaction was studied over the temperature ranges (20, 25, 30, 35)°C. In both solvents, enhancement of temperature increased the rate constants (Table 2).

Both the Arrhenius Equation (5) and Eyring Equation (6) describe the temperature dependence of reaction rates.

$$lnk_{obs}^{a} = lnA - \frac{E_{a}}{RT}$$
(5)

$$ln\frac{k_{obs}^{a}}{T} = -\frac{\Delta H^{\ddagger}}{RT} + \frac{\Delta S^{\ddagger}}{R} + ln\frac{k_{B}}{h}$$
(6)

The slope and the intercept of the linear Arrhenius plot (Figure 6, Equation (5)) are equal to the activation energy and collision frequency, respectively.

The activation enthalpy (ΔH^{\ddagger}) and entropy (ΔS^{\ddagger}) could be extracted for the reaction **a** from the slope and the intercept of the Eyring plot (Equation (6), Figure 7). The activation parameters are accumulated in Table 3. The Gibbs activation energy ΔG^{\ddagger} is related to ΔH^{\ddagger} and $(T\Delta S^{\ddagger})$ terms, when $|T\Delta S^{\ddagger}|$ value is bigger than ΔH^{\ddagger} value, so the reaction is entropy-controlled. Conversely, the reactions with the ΔH^{\ddagger} value higher than $|T\Delta S|^{\ddagger}$ named enthalpy-controlled. Herein, the reaction is entropy-controlled in both solvents. It means that the favorable low enthalpy, ΔH^{\ddagger} , values (Table 3) compensates the unfavorable large negative entropy, ΔS^{\ddagger} , values.

A comparison of the activation energy and collision frequency (A) in acetonitrile indicated that favorable high collision frequency compensates the unfavorable high activation energy, Ea, for achievement of the reaction easily, conversely in methyl ethyl ketone solvent, the unfavorable low collision frequency can be compensates by the favorable low activation energy, Ea, to facilitate the reaction.

The effect of both substituents 4-chloro and 4-methyl was investigated by para-substituted benzoyl isothiocyanate (1) on the reaction rate in acetonitrile solvent, and it was found that 4-chloro substituents group increases the reaction rate, but 4-methyl substituent decreases the rate (1) (Table 4). Electronwithdrawing substituent group like 4-chloro on benzoyl isothiocynate ring (1) develops the positive charge at the reaction center (see Scheme 2, reaction **a**), which would be delocalized by a moderate nucleophile such as 1-naphthylamine (2), this feature tends to increase the reaction rate. Conversely, electron-donating group reduces the positive charge at the reaction center, so its tendency is reduced to react with a moderate nucleophile.

Section 2

Determination of the experimental rate law in the reaction b

In this section, the kinetics and mechanism of the reaction **b**, among thiourea (P_1), methyl bromoacetate (3) and triethylamine (4) were investigated in acetonitrile (reaction **b** Scheme 2). First, the two components (1) and (2) with suitable concentrations (10^{-2} M) were mixed for 15 min outside of the uv cell to generate approximately 10^{-2} M solution of P_1 component.

Then 10^{-2} M of each component (3) and (4) were added to approximately 10^{-2} M of mixture solution (P₁). Periodic scanning of UV spectra of the reaction mixture initiates at 5 min intervals up to 60 min for the generation of thiazole (5) as a final product. UV-vis spectra were continuously recorded until the reaction was completely carried out (Figure 8).

During the reaction's progress (reaction **b**), a decrease in absorbance was observed over the wavelengths of 380-420 nm range, which is likely due to absorbance decay of the reactant P_1 in reaction **b** (earlier, enhancement of

Table 3. Activation parameters (ΔH^{\dagger} , ΔS^{\dagger} , ΔG^{\dagger} , Ea and A) at 20 °C for the reaction a between (1), (2).

	$\Delta { m H}^{\ddagger}~{ m kJ}~{ m mol}^{-1}$	$\Delta { m S}^{\ddagger}$ J mol $^{-1}{ m K}^{-1}$	$T\Delta S^{\ddagger} kJ mol^{-1}$	$\Delta { m G}^{\ddagger}~{ m kJ}~{ m mol}^{-1}$	$E_a kJ mol^{-1}$	A M ⁻¹ min ⁻¹
Acetonitrile ($\varepsilon = 37.5 \text{ D}$)	19.7 ± 0.7	-143.48 ± 2.26^{b}	-41.77	61.53 ± 1.35	22.3 ± 0.7	$5.51 imes 10^5$
Methyl ethyl ketone ($\varepsilon = 18.22$ D)	9.7 ± 0.3	-184.49 ± 1.07	-53.71	63.38 ± 0.6	12.2 ± 0.3	3.98×10^{3}

^berror standard was calculated corresponding to Lente method.^[34]

Table 4. The substituents effects on the rate constant k_{obs}^a of the reaction **a**, between para-substituted benzoyl isthiocyanate (1) and 1-naphthylamine (2) at 20 °C.

p-substituted benzoyl isocyanate (1)	k_{obs}^a M ⁻¹ min ⁻¹
Cl	104.8± (0.0012)
Н	59.90± (0.001)
CH ₃	42.93± (0.0016)
^a SD.	

absorbance has been seen for the formation of P_1 in the same approximately range in reaction **a**, Figure 1).

In the other experiment at 20°C, the change in absorbance was monitored against time in 395 nm under same condition with previous experiment, Figure 9. The second-order fitting curve (solid curve) was exactly fitted on the experimental absorbance curve (dotted curve) by the associated software within the program.^[33] A good fitting curve showed that the reaction follows second-order kinetics ($\delta + \gamma = 2$).

The rate laws can be written in the following form

Rate =
$$k_{ove}[\mathbf{P}_1]^{\gamma}[\mathbf{3}]^{\delta}[\mathbf{E}\mathbf{t}_3\mathbf{N}]^{\lambda}$$
 (7)

Triethylamine is a typical catalyst for this reaction, so its concentration is constant;

Rate =
$$k_{ove}[P_1]^{\gamma}[3]^{\delta}[Et_3N]^{\lambda}$$
 $k_{obs}^b = k_{ove}[Et_3N]^{\lambda}$
Rate = $k_{obs}^b[P_1]^{\gamma}[3]^{\delta}$ (8)

The overall order of the reaction b is the sum of $\gamma + \delta = 2$.

 k_{ove} refer to overall rate constant of reaction **b** among (**P**₁), (3) and Et₃N.

 k_{obs}^{b} refer to observational rate constant of reaction **b** between (**P**₁) and (**3**), Equation (8).

Under pseudo-order condition $[([3] = 10^{-2}M)]$ and $[P_1] = 5 \times 10^{-3}M$, Equation (8) is convert to Equation (8'):

$$k_{obs}^{b}[3]^{\delta} = k_{obs}^{b'}$$
 and then Rate $k_{obs}^{b'}[P_{1}]^{\gamma}$ (8')

The experimental absorbance curve shown in Figure 10 (dotted), is relevant to the mathematical Equation (8') which is properly fitted on the first-order fitting curve (solid). It means that partial order of (P₁) is one ($\gamma = 1$). In the previous experiment, the sum of $\delta + \gamma$ was 2 ($\delta + \gamma = 2$), therefore partial order of bromoacetate (3) is one ($\delta = 1$).

Herein, although the twofold excess of (P_1) was practically used in this experiment, it was too enough to achieve pseudoorder condition, since changes in absorbance was considerably high ($\Delta A = 0.4$) to record properly absorbance data (Figure 10).

So the rate law can be written for the reaction **b** as:

$$Rate_{\mathbf{b}} = k_{obs}^{\mathbf{b}}[P_1] [3]$$
(9)

In section 1, demonstrated that rate low for the reaction **a**, can be written as $\operatorname{rate}_{a} = k_{obs}^{a}$ [1] [2]. In this section, the rate low obtained for the reaction **b** as $\operatorname{rate}_{\mathbf{b}} = k_{obs}^{b}$ [P₁][3].

Since, reactants (1, 2) and (3) are components of overall reaction and P_1 is the product that generated in the reaction **a** and subsequently consumed in the reaction **b**, thus a combination of rate_a and rate_b can be expressed:

$$Rate_{exp} = k_{obs}[1][2][3]$$
 (10)

Therefore, the reaction is third-order kinetics, and k_{obs} refers to observational rate constant for three component reaction among components (1, 2) and (3).

Effects of solvent, temperature and substituent in the reaction b

We also tested the effect of electron-donating and withdrawing substitutions such as 4-methyl and 4-chloro on para position of 1-benzoyl-3-(naphthalene-1-yl) thiourea (P_1). The chloro substituent increased the rate constant (4.67 M⁻¹ min⁻¹), but methyl substituent approximately did not effect on the rate constant (2.03 M⁻¹min⁻¹) versus (1.94 M⁻¹min⁻¹, unsubstituent of (P_1) compound) (see Table 5).

Herein, electron-withdrawing groups (EWS) on benzoyl group of $(\mathbf{P_1})$ (in addition to both carbonyl and thio-groups) reduce the N₁-H strength (near the EWS) and subsequently increase the nucleophilicity of sulfur atom to facilitate the rate of nucleophilic reaction between reagents ($\mathbf{P_1}$) and (3) in the presence of catalyst (4) (step₂, reaction **b**, Scheme 3). On the contrary, electron-donating groups (EDS) tend to reduce the rate of nucleophilic reaction, since relatively increase the N₁-H strength and reduce the nucleophilicity of sulfur atom.

Herein, higher polar solvent stabilized the charges in transition state $(TS_2, step_2)$ more than the reactants with the lack of charge ((P1) and (3)), so high polar solvent and temperature increased the nucleophilic reaction rate, the results were reported in Table 6.

The activation parameters evaluated according to the Arrhenius and Eyring plots (Figure 11) and shown in Table 7. The reaction is entropy-controlled in methyl ethyl ketone and enthalpy-controlled in acetonitrile. Evaluation of (ΔH^{\dagger}) and (ΔS^{\dagger}) values indicate that activation enthalpy in the acetonitrile solvent is more than the methyl ethyl ketone, and the activation entropy in the acetonitrile solvent $\Delta S^{\dagger} = (-48 \text{ Jmol}^{-1}\text{K}^{-1})$ is considerably positive in relation to methyl ethyl ketone $\Delta S^{\ddagger} = (-143.48 \text{ Jmol}^{-1}\text{K}^{-1})$, thus low enthalpy, ΔH^{\ddagger} , value is favorable in methyl ethyl ketone solvent and compensates the unfavorable negative entropy, ΔS^{\ddagger} , value, while high enthalpy, ΔH^{\ddagger} , value is unfavorable in acetonitrile solvent and can be compensated by the favorable (positive in comparison with methyl ethyl ketone) entropy value (ΔS^{\ddagger}).

$$ln(k_{obs}^{b}) = lnA - \frac{E_a}{RT}$$

$$ln\frac{k_{obs}^{o}}{T} = -\frac{\Delta H^{\ddagger}}{RT} + \frac{\Delta S^{\ddagger}}{R} + ln\frac{k_{B}}{h}$$



Figure 8. A) Absorbance changes against wavelengths for the reaction b among 1-benzoyl-3-(naphthalene-1-yl) thiourea) (P_1) (10⁻² M), methyl bromoacetate (3) (10⁻² M) and triethylamine (4) (10⁻² M) in acetonitrile for the generation of thiazole at 5 min intervals up to 60 min; the downward arrow shows the direction of the reaction's progress; B) The UV spectra of three single components (3, 4) and (P_1) [10⁻² M of each compound] in acetonitrile solvent which have been collected in the same chart.



Figure 9. Dependence of absorbance against time in the reaction **b**, between (P_1) (10^{-2} M), (**3**) (10^{-2} M) and (**4**) (10^{-2} M) in 395 nm wavelength, the dotted curve shows the experimental absorbance values, and the solid line is the second-order fitting curve.



Figure 10. Absorbance dependence versus time, in the reaction **b** among 1-benzoyl-3-(naphthalene-1-yl) thiourea (**P**₁) (5×10^{-3}), in the presence of excess methyl bromoacetate (**3**) and triethylamine (**4**) (10^{-2}) in 395 nm, the dotted curve shows the experimental absorbance values, and the solid line is the first-order fitting curve at 20°C.

Mechanism

From the experimental results of reactions **a** and **b**, and also reports in the literature,^[20] a mechanism containing four step proposed as follows:

Table 5. The substituents effects on the rate constant (k_{obs}^b) of the reaction **b** among P-substituted thiourea (**P**₁), (**3**) and (**4**) at 20°C.

P-substituted thiourea (P1)	k_{obs}^{b} (M ⁻¹ min ⁻¹)
CI	4.67
Н	1.94
CH ₃	2.03

The above mechanism is a combination of reaction **a**, with step₁ and reaction **b**, involving step₂, step₃ and step₄. By consideration of each step as the rate-determining step (RDS) and applying steady-state approximation, only assumption of step₂ (k_2) as RDS gave a rate_{mech} law^[12] [see Supplemental Materials], that was consistent with the experimental rate_{exp} law, Equation (10).

$$rate_{mech} = \frac{k_{obs}^{a} k_{2}}{k_{-1}} [1][2][3][Et_{3}N] k_{obs} = \frac{k_{obs}^{a} k_{2}[Et_{3}N]}{k_{-1}}$$
(11)

$$rate_{mech} = k_{obs}[1][2][3]$$
 (12)

As can be seen, the rate constant (k_2) of the rate-determining step (step₂) contributes in k_{obs} , Equation (11), accompanied by the rate constant (k_{obs}^a) of step₁. In the experimental sections, these rate constants (k_{obs}^a, k_2) can be increased with polar solvent and electron-withdrawing groups, because they belong to the RDS of both reaction **a** and reaction **b**, respectively. k_3 and k_4 had no effect on the reaction rate since they participate in fast steps. Moreover, extremely large negative entropy, ΔS^{\ddagger} , values in both Tables 3 and 7 had a considerable agreement with step₁ (k_{obs}^a) and step₂ (k_2) , because in each step two components in ground state are converted to one unit in the transition state. This feature, has a different behavior and a reverse action in step₃ (k_3) and step₄ (k_4) , respectively.

Conclusion

The kinetics and mechanism of Z-N-(3-(naphthalene-2-yl)-4-oxothiazolidine-2-ylidene) benzamide formation (5) were

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X:H, NO2, CH3, OCH3, CI

Scheme 3. The speculative mechanism for the reaction among (1), (2), (P1), (3) and (4) for the generating (5).

Table 6. Reaction rate constants (k_{obs}^{b} M⁻¹min⁻¹) at different temperatures (±0.1) under the same conditions for the reaction b, between (P₁) (10⁻² M), (3) (10⁻² M) and (4) (10⁻² M).

	20	25	30	35
Acetonitrile ($\varepsilon = 37.5 \text{ D}$)	$1.9\pm(0.0037)^{a}$	2.9±(0.002)	4.3±(0.002)	6.2±(0.0012)
Methyl ethyl ketone ($\varepsilon = 18.22$ D)	0.3±(0.002)	0.36±(0.0016)	0.47±(0.0013)	0.60±(0.0032)
-				

^astandard deviation.



Figure 11. Arrhenius plot ($ln k_{obs}^b$ aginst 1/T) and Eyring plot ($ln k_{obs}^b/T$ versus 1/T) for the reaction between reactants (P_1), (3) and (4) in various solvents for the reaction **b**.

Table 7. Activation parameters (ΔH^{\dagger} , ΔS^{\dagger} , ΔG^{\dagger} , Ea and A) at 20 °C for the reaction b between (P₁), (3) and (4).

	$\Delta H^{\ddagger} \text{ kJ mol}^{-1}$	$\Delta S^{\ddagger} Jmol^{-1}K^{-1}$	$T\Delta S^{\ddagger} kJ mol^{-1}$	ΔG^{\ddagger} kJ mol $^{-1}$	Ea kJ mol ⁻¹	A M ⁻¹ min ⁻¹
Acetonitrile Mothyl othyl kotopo	55.9 ± 0.18	-48 ± 0.6^{b}	-14.06	70.00 ± 0.36	58.4 ± 0.18	5.07×10^{10} 5.25 × 10 ⁵
Methyl ethyl ketone	52.7 ± 0.28	-145.46 ± 0.95	-41.60	74.40 ± 0.55	55.2 ± 0.28	5.55 × 10

^berror standard was computed based on Lente method.^[34]

studied by the UV-vis spectrophotometry, for the first time. The reaction kinetics can be well described by third-order rate expression. Based on the experimental results, a mechanism was proposed with a combination of reaction **a**, containing step₁ (k_{obs}^a) and also reaction **b**, involving step₂ (k_2), step₃ (k_3) and step₄ (k_4). The rate of reaction **a**, was more than the reaction **b** (Tables 2 and 6). The second step (k_2) of reaction **b** controlled the overall kinetics of the reaction (equation 11, $k_{obs} = \frac{k_{obs}^a}{k_{c1}} \frac{k_2 [\text{Et}_3 \text{N}]}{k_{c1}}$), according to kinetic analysis of the following data:

The kinetic analysis of the reaction revealed that the rate constants $(k_{obs}^{a}, k_{2} \text{ and subsequently } k_{obs})$ were increased by the electron-withdrawing substituent groups in both reaction a, and b, (Tables 3-5) and higher polar solvent (Tables 2 and 6), but were decreased in the solvent with low dielectric constant. k_3 and k_4 had never chance for being a rate-determining step (RDS) in this competition, because they did not appear in the equation 11 (k_{obs}) and belong to the fast steps (step₃ and step₄). Moreover, the extremely large and negative ΔS^{\ddagger} values in both reaction **a** and **b** in Tables 3 and 7 had a considerable agreement with step₁ (k_{abs}^a) and step₂ (k_2) , because in both step₁ and step₂ two compounds in ground state are converted to one unit in the transition states (TS1 and TS2), an associative mechanism with a remarkable negative activation entropy ($\Delta S^{\ddagger} \ll 0$). The sum of these experimental observations is compatibile with the second step (k_2) . Therefore, k_2 has a good capability for being the RDS. It seems that the most important steps in the reaction mechanism are step₁ (k_{abs}^a) and step₂ (k_2) which strongly control the reaction process.

Chemicals and apparatuses used

All acquired chemicals were used without further purification. Reactants were supplied by Merck (Darmstadt, Germany), Acros (Geel, Belgium) and Fluka (Buchs, Switzerland). Extra pure acetonitrile and methyl ethyl ketone were also supplied by Merck (Darmstadt, Germany). A Cary UV-vis spectrophotometer model Bio-300 with a 10 mm light-path quartz spectrophotometer cell equipped with a thermostatted housing cell was used to record the change in absorbance spectra of the reaction

Disclosure statement

No potential conflict of interest was reported by the authors.

Funding

We gratefully acknowledge financial support from the Research [Council of the University of Sistan and Baluchestan.

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