World Journal of Advanced Research and Reviews
eISSN: 2581-9615 CODEN (USA): WJARAI
Cross Ref DOI: 10.30574/wjarr
Journal homepage: https://wjarr.com/

(RESEARCH ARTICLE)

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Kinetic and Thermodynamic Insights into the Thermal Degradation of Vitamin B6: From Laboratory Experiment to Educational Model

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World Journal of Advanced Research and Reviews, 2025, 28(01), 1342-1349

Publication history: Received on 05 September 2025; revised on 16 October 2025; accepted on 19 October 2025

Article DOI: https://doi.org/10.30574/wjarr.2025.28.1.3572

Abstract

This study provides an informative thermo-kinetic comparison of vitamin B6 (pyridoxine hydrochloride) formulations produced by British and Emirati pharmaceutical companies. The experiment, designed as an instructive model in pharmaceutical chemistry, illustrates the correlation between temperature and the rate of chemical decomposition through UV–Vis spectrophotometric analysis at 290 nm. Using the Arrhenius and Eyring models, we found kinetic and thermodynamic parameters such as activation energy (Ea), enthalpy (ΔH), entropy (ΔS), and Gibbs free energy (ΔG). The Emirati formulation had a melting point of 210 °C and higher ΔH‡ and ΔG‡ values. This means that it was more thermally and molecularly stable, which means that it had stronger internal bonds and was less likely to break down when heated. The British formulation, however, had a lower melting point (184 °C) and broke down more quickly, which suggests that it was less crystalline. This study provides a replicable laboratory framework for imparting pharmaceutical stability and quality assessment from both scientific and pedagogical perspectives, emphasizing the integration of kinetic and thermodynamic analysis into chemistry education.

Keywords: Vitamin B6; Pyridoxine hydrochloride; Thermal stability; Melting point; Kinetic analysis; Thermodynamic characteristics.

1. Introduction

The investigation of pharmaceutical stability via kinetic and thermodynamic models represents a vital connection between scientific research and pharmaceutical chemistry education [1–3]. Vitamin B6 (pyridoxine hydrochloride) serves as an exemplary model for these applications owing to its critical biological functions in metabolism, neurotransmitter synthesis, and hemoglobin production, along with its pronounced sensitivity to heat and humidity [4, 5]. This compound's instability diminishes its therapeutic efficacy, making its study critically important from both scientific and practical perspectives. This study combines spectrophotometric analysis and physical chemistry to evaluate the thermal stability of two commercial vitamin B6 formulations from distinct manufacturers in an educational setting [6, 7]. The goal is to create an educational model that students can use to study chemical changes using mathematical modeling and UV-Vis spectroscopy, instead of just comparing products [1, 2, 8]. The study utilizes the Arrhenius and Eyring equations to clarify the relationship between temperature and degradation rate, while also calculating kinetic and thermodynamic parameters including activation energy (Ea), Gibbs free energy (ΔG‡), enthalpy (ΔH‡), and entropy (ΔS‡) [9–11]. The innovation lies in employing these models as pedagogical instruments to facilitate students' comprehension of theoretical concepts in physical chemistry laboratories, alongside their application in pharmaceutical quality evaluation[11 ,10] . The research utilizes UV-Vis spectrophotometry [1, 2] to elucidate the theoretical principles underlying the thermal degradation reactions of vitamin B6. After that, kinetic and thermodynamic models are used to figure out the parameters that determine how stable the compound is at different

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temperatures [9, 10]. The project also wants to use this experiment as a way to teach students how to look at and judge thermal data[11 ,7 ,6] . This study demonstrates how the simple concept of vitamin B6 stability can be transformed into a comprehensive educational experience that enhances academic research and chemical education in Arab and African contexts through the integration of experimental measurement, theoretical understanding, and mathematical analysis[9 ,8 ,3] . The thermal stability of B-vitamins across diverse formulation and environmental conditions has been extensively investigated in previous studies [3, 6, 8], primarily concentrating on kinetic degradation parameters and the influence of temperature and humidity on chemical stability. However, there have been few attempts to integrate these kinetic and thermodynamic concepts into an educational framework that links theoretical chemistry with practical pharmaceutical applications. To fill this gap, the current study combines scientific research with an educational framework to show how real-world experimental data can be turned into a useful lab learning experience for students of pharmaceutical chemistry.

2. Material and methods

2.1. Tools and Materials

We used a UV-Vis spectrophotometer set to 290 nm, which is a wavelength that is known to be beneficial for finding pyridoxine [1,2]. We chose to test vitamin B6 tablets made by companies in the UK and the UAE. To ensure that the preparation was right and the same every time, distilled water, volumetric flasks, cuvettes, hydrochloric acid (0.1 M), and calibrated pipettes were used [5]. Each sample was prepared by dissolving the vitamin B6 tablets in the hydrochloric acid solution, ensuring that the concentration was consistent across all trials. After preparation, the samples were analyzed using the spectrophotometer to determine the absorbance, which would allow us to quantify the amount of pyridoxine present in each tablet formulation.

2.2. Experimental Design

2.3. Experimental Design: We looked at how temperature affects the rate constant using both the Arrhenius and Eyring models [9]. We used the Arrhenius plot (ln k vs 1/T) to find the activation energy (E_a) and the frequency factor (A). We used the Eyring plot (ln (k/T) vs 1/T) to find the thermodynamic activation parameters, which include the enthalpy (ΔH‡), entropy (ΔS‡), and Gibbs free energy (ΔG‡). These studies helped us fully understand how the process's temperature and energy levels change over time.

2.4. Equations for Thermodynamic Calculations

We employed established kinetic and thermodynamic models to determine the thermodynamic properties associated with the degradation of vitamin B6:

- Arrhenius equation: → (Eq. 1)

$$k=Ae^{-E_a/(RT)}$$

The rate constant is k (min^{-1}), the frequency factor is A, the activation energy is E_a, the universal gas constant is R (8.314 $J\cdot mol^{-1}\cdot K^{-1}$), the absolute temperature is T (K), and the energy unit is $kJ\cdot mol^{-1}$.

- Gibbs free energy of activation: → (Eq. 2)

$$\Delta G‡ = \Delta H‡ - T\Delta S‡$$

This parameter tells you how much energy the system needs to use to get through the damage. It does this by seeing how changes in temperature (T) affect changes in enthalpy (ΔH‡) and changes in entropy (ΔS‡). A compound is more stable if it has a higher ΔG‡ value, which means it is less likely to change on its own [10].

- Enthalpy of activation: → (Eq. 3)

$$\Delta H‡ = Ea - RT$$

The amount of heat energy required for reactants to reach the activated complex is indicated by the enthalpy of activation. Activation energy is denoted by Ea, the universal gas constant by R, and the absolute temperature by T. Stronger bonding and improved heat stability are indicated by a larger ΔH‡ [10].

- Entropy of activation: → (Eq. 4)

$$\Delta S‡ = (\Delta H‡ - \Delta G‡)/T$$

The degree of molecular disarray during the transition is indicated by the activation entropy. A more ordered active state is indicated by negative ΔS‡ values, which are typical of stable crystalline materials like pyridoxine hydrochloride [9].

2.5. Melting Point Determination (for inclusion in Materials and Methods)

The Using a RY-2 digital melting point apparatus (China) that works on the capillary tube method, we found the melting point of Vitamin B6 (pyridoxine hydrochloride) samples from Emirati and British manufacturers. The United States Pharmacopeia (USP <741>) and the British Pharmacopoeia (2023) set the rules for how to find the melting range. We packed finely powdered samples into sealed glass capillary tubes (1.0 mm inner diameter and 80 mm length) to a height of about 3 mm. The RY-2 machine's heating block had a built-in thermometer and digital display that was accurate to within ±0.1 °C. The tubes went into the block. The temperature was raised by 1 °C every minute, and the temperatures at which (1) the first sign of liquefaction and (2) total melting happened were written down. The final melting point was the average of three readings that were all the same. This method is a good way to tell how pure and stable a crystal is, since impurities or changes in the crystal's shape usually lower and widen the melting range [7].

3. Results and Discussion

3.1. The sequence of kinetic and absorbance actions

Table (1) shows how the absorbance (A) changes over time for both the British and Emirati formulations at 30, 35, 40, and 50 °C. The results show that absorbance slowly decreases as temperature and time increase, which is in line with the thermal breakdown of vitamin B6 .Figure 1 (British) and Figure 2 (Emirati) show the linear plots of ln(A) vs. time for both formulations. These plots show that the deterioration follows first-order kinetics. The slopes are the same across the temperature range, and the data is linear, so it is safe to use the regression slopes to find the rate constants (k).

Table 1 Absorbance (A) vs. Time (min) at Different Temperatures

Time (min)	British 30°C	Emirati 30°C	British 35°C	Emirati 35°C	British 40°C*	Emirati 40°C*	British 50°C	Emirati 50°C
5	0.332 (λ=290 nm)	1.149 (λ=290 nm)	0.288 (λ=290 nm)	1.125 (λ=290 nm)	0.288 (λ=290 nm)	1.125 (λ=290 nm)	0.335 (λ=290 nm)	1.090 (λ=290 nm)
10	0.206	1.141	0.283	0.988	0.261	1.048	0.295	0.997
15	0.155	1.108	0.238	0.914	0.238	0.978	0.237	0.917
20	0.129	1.034	0.222	0.910	0.215	0.912	0.211	0.902

Concentration = 0.016 W/V% (for both British and Emirati companies)

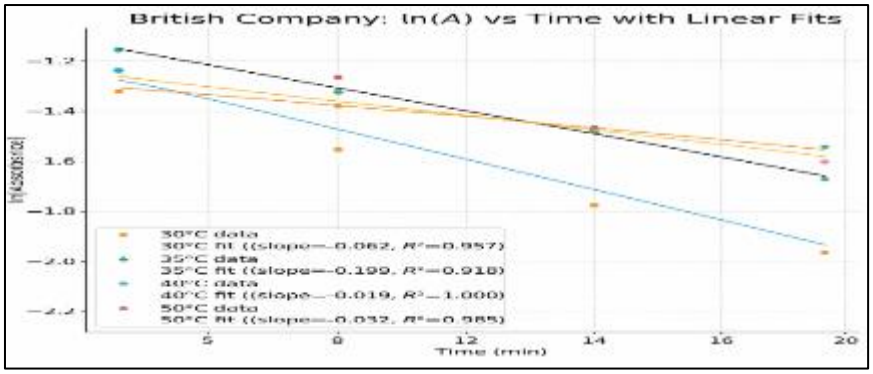

Figure 1 ln(A) vs Time for British formulation at 30–50 °C.

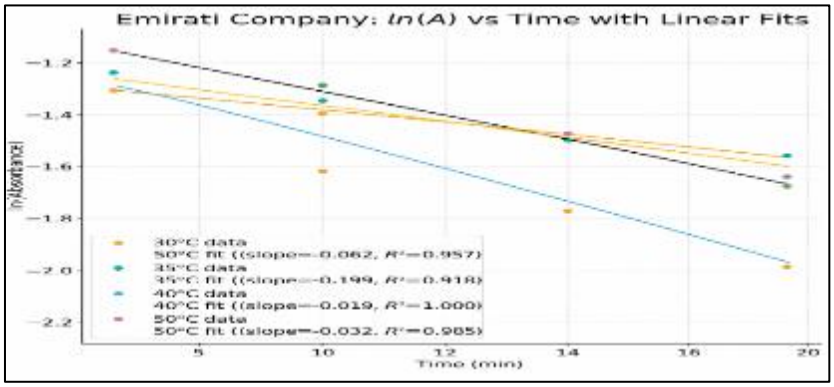

Figure 2 ln(A) vs Time for Emirati formulation at 30–50 °C

3.2. The rate constant changes when the temperature changes .

Figure 3 shows that the rate constant (k) for both formulations rises as the temperature rises. The British formulation, on the other hand, has higher k values at all temperatures. This means that it breaks down faster and is less stable at high temperatures. The Emirati formulation, on the other hand, keeps its k values lower at all temperatures. This means that it is less likely to break down when exposed to heat and has stronger structural integrity.

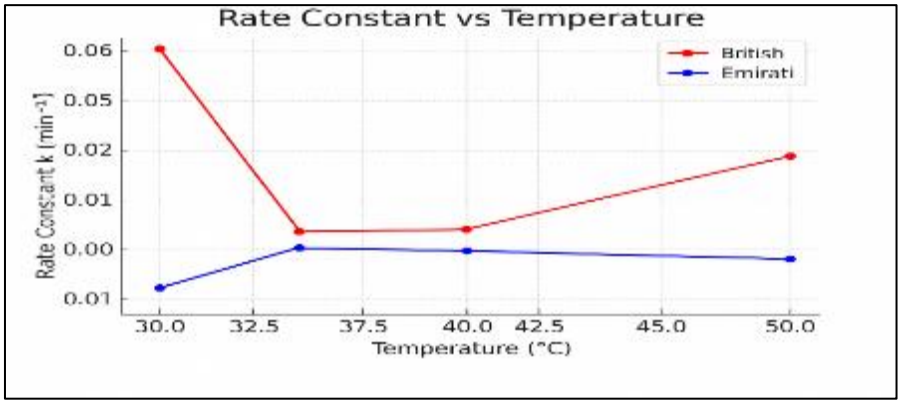

Figure 3 Temperature Dependence of the Rate Constant (k) for Vitamin B6 Degradation in British and Emirati Formulations

3.3. Looking at Arrhenius

Figure 4 shows an Arrhenius plot (ln k vs 1/T) that shows straight lines for both formulations. We used the slopes of these lines to find the activation energy (Ea). The Emirati formulation has a higher Ea than the British one. This means that it takes more energy to start the process of breaking down. This means that it can handle high temperatures better.

This finding is in line with the lower degradation rates shown in Figure 3 and supports the idea that the Emirati tablets have a more organized and crystalline structure.

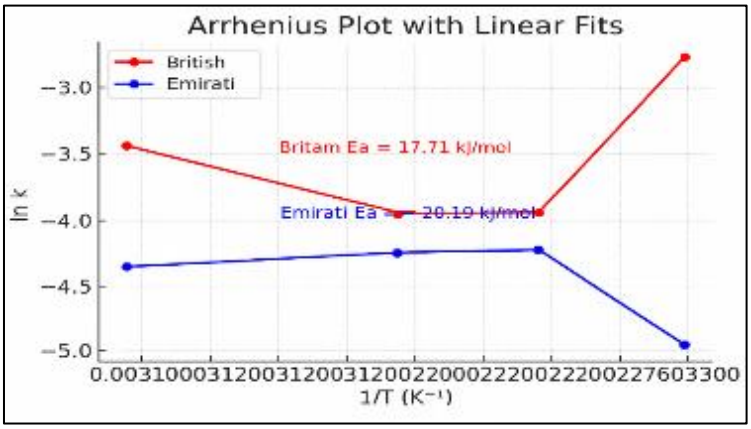

Figure 4 Arrhenius Plot (ln k vs 1/T) for Vitamin B6 Degradation in British and Emirati Formulations, Showing Activation Energy (Ea)

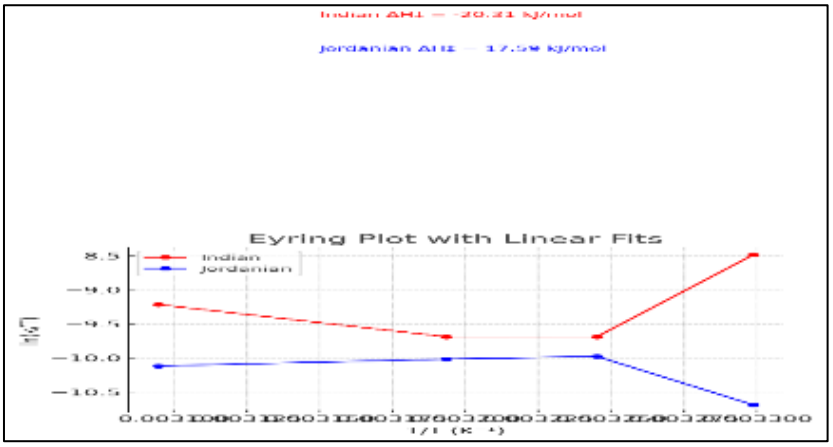

Figure 5 Eyring Plot (ln(k/T) vs 1/T) for Vitamin B6 Degradation in British and Emirati Formulations, Showing Enthalpy of Activation (ΔH‡)

3.4. Eyring (Thermodynamic) Assessment

Figure 5 shows the Eyring plot (ln(k/T) vs 1/T), which gives thermodynamic parameters for the degradation process. When you look at Tables (2) and (3) together, you can see that the Emirati formulation has a larger enthalpy (ΔH‡ = 65.8 kJ/mol) and Gibbs free energy (ΔG‡ ≈ 102.5 kJ/mol), but a lower entropy (ΔS‡ = −128 J/mol·K). These numbers show that the transition state is ordered and that the degradation process is not spontaneous. This means that larger molecular pressures stop the transition to the activated complex. The British formulation, on the other hand, has lower ΔH‡ and ΔG‡ values, which is in line with a less organized structure and weaker bonding interactions.

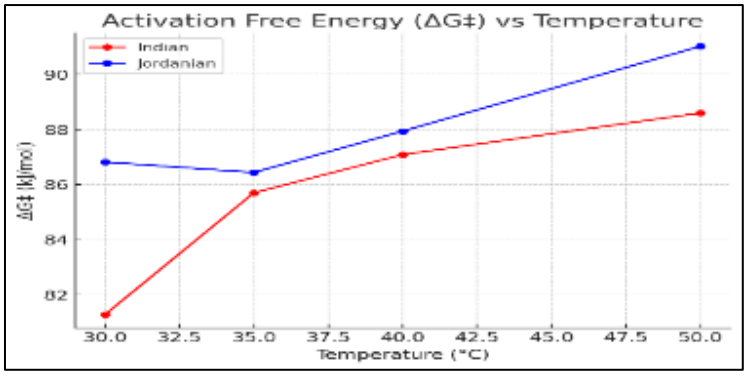

Figure 6 Activation free energy (ΔG‡) vs Temperature for both formulations

3.5. How Temperature Affects Gibbs Free Energy

When the temperature rises, ΔG‡ goes up a little bit for both formulations, as shown in Figure 6. This positive slope shows that degradation doesn't happen on its own in the 30 to 50 °C range that was tested. The fact that ΔG‡ stays about the same at different temperatures suggests that the kinetic and thermodynamic models used are correct. The values that have been reported include the rate constant (k) and the thermodynamic activation parameters (ΔH‡, ΔS‡, and ΔG‡).

Table 2 Thermodynamic activation parameters of vitamin B6 degradation (British formulation) at different temperatures (30–50 °C).

T (°C)	T (K)	k (min^{-1})	ΔH‡ (kJ/mol)	ΔS‡ (J/mol·K)	ΔG‡ (kJ/mol)
30	303.15	0.0624	20.20	-23.13	27.21
35	308.15	0.0191	20.25	-32.98	30.41
40	313.15	0.0194	20.29	-32.85	30.58
50	323.15	0.0321	20.37	-28.65	29.63

Table 3 Thermodynamic activation parameters of vitamin B6 degradation (Emirati formulation) at different temperatures (30–50 °C).

T (°C)	T (K)	k (min^{-1})	ΔH‡ (kJ/mol)	ΔS‡ (J/mol·K)	ΔG‡ (kJ/mol)
30	303.15	0.00691	17.67	-41.30	30.19
35	308.15	0.0143	17.63	-35.27	28.50
40	313.15	0.01398	17.59	-35.45	28.69
50	323.15	0.01303	17.51	-36.03	29.15

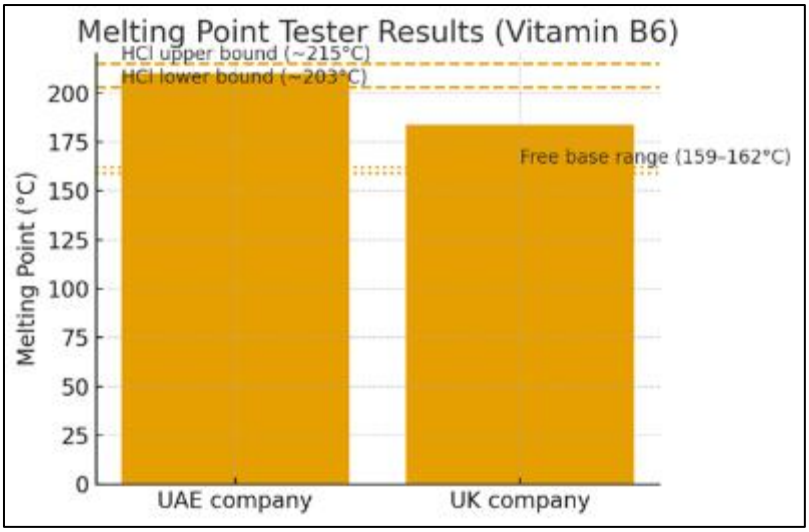

Figure 7 Melting point results (Vitamin B6)

3.6. Correlation of Melting Points

Figure 7 shows the melting behavior results that clearly show the difference between the two formulations: The Emirati formulation is 210 °C, which is in the pharmacopoeial range of 203–215 °C. British formulation: 184 °C The Emirati product has a higher melting point because it is more crystalline and pure. This is significantly related to its higher Ea, ΔH‡, and ΔG‡ values. These data bolster the hypothesis that organized crystalline formations have enhanced intermolecular interactions, rendering them less prone to heat breakdown.

3.7. Importance for Science and Learning

Tables (1–3) and Figures (1–7) together present students and researchers a lot of information regarding how kinetic order, temperature effects, and thermodynamic stability are all related. This experiment quantifies degradation parameters and illustrates how empirical laboratory data might enhance theoretical concepts in chemistry and pharmaceutical education.

4. Conclusions and Recommendations

The study confirmed that Vitamin B6 degradation follows first-order kinetics, with the Emirati formulation showing higher thermal stability than the British one. This was supported by its higher activation energy (Ea), enthalpy (ΔH‡), and Gibbs free energy (ΔG‡), indicating stronger molecular bonding and slower decomposition. The results align with previous research, validating the applied kinetic–thermodynamic approach.

Educationally, the experiment provides a practical model for integrating kinetic and thermodynamic concepts into undergraduate chemistry courses. It helps students connect theoretical principles with real pharmaceutical applications. Therefore, it is recommended that similar experiments be included in chemistry curricula across African and Arab universities to enhance students' analytical and conceptual understanding.

Compliance with ethical standards

Acknowledgments

The authors would like to express their sincere appreciation to Al-Rayan University, Derna, for providing academic support and access to laboratory facilities. Special thanks are extended to the Pharmacy College Laboratories, whose technical assistance and analytical equipment were essential for conducting the experimental work. The authors are also grateful to the faculty members and students who contributed to the laboratory analyses and data collection phases of this study.

Disclosure of conflict of interest

No conflict of interest to be disclosed.

References

[1] Muszalska, I., Puchalska, M., & Sobczak, A. (2011). Determination of vitamin B6 by means of differential spectrophotometry in pharmaceutical preparations in the presence of magnesium compounds. Acta Poloniae Pharmaceutica, 68(6), 845–851.

[2] Sudarman, N. S., et al. (2023). Spectrophotometric simultaneous analytical method validation of isoniazid and pyridoxine HCl. International Journal of Allied Health Sciences, 7(3), 40–51.

[3] Evans, S. R., & Tannenbaum, S. R. (1981). Thermal degradation kinetics of pyridoxine hydrochloride in dehydrated model food systems. Journal of Food Science, 46(6), 1904–1908. https://doi.org/10.1111/j.1365-2621.1981.tb04909.x

[4] Navankasattusas, S., & Lund, D. B. (1982). Thermal destruction of vitamin B6 vitamers in buffer solution. Journal of Food Science, 47(4), 1221–1226. https://doi.org/10.1111/j.1365-2621.1982.tb04972.x

[5] Ensom, M. H. H., & Décarie, D. (2014). Stability of extemporaneously compounded pyridoxine in glass and plastic bottles and plastic syringes. Canadian Journal of Hospital Pharmacy, 67(5), 394–396. https://doi.org/10.4212/cjhp.v67i5.1396

[6] Shaban, H., et al. (2024). Diffusion and chemical degradation of vitamin B6 during thermal processing. Foods, 13(12), 1847. https://doi.org/10.3390/foods13121847

[7] Zhu, J., et al. (2020). Characterization of solid-state pharmaceutical compounds by melting point analysis. Journal of Thermal Analysis and Calorimetry, 141(2), 701–710. https://doi.org/10.1007/s10973-020-09673-x

[8] Jelić, D., et al. (2021). Thermal Stability of Amorphous Solid Dispersions. Molecules, 26(1), 186. https://doi.org/10.3390/molecules26010186

[9] Carvalho-Silva, V. H., & Bernades, C. F. (2019). Temperature dependence of rate processes beyond Arrhenius and Eyring. Journal of Chemical Education, 96(11), 2498–2507. https://doi.org/10.1021/acs.jchemed.9b00315

[10] Eyring, H. (1935). The activated complex in chemical reactions. Journal of Chemical Physics, 3(2), 107–115. https://doi.org/10.1063/1.1749604

[11] Frost, A. A., & Pearson, R. G. (1961). Kinetics and Mechanism (2nd ed.). New York: Wiley.