

Photo degradation of Crystal Violet Dye from The Aqueous Phase by Cao-g-C₃N₄ Nano catalyst

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Abstract

The presence of synthetic dyes such as Crystal Violet (CV) in aquatic environments presents significant environmental and public health concerns due to their toxic nature and resistance to traditional remediation techniques. In this work, a calcium oxide and graphitic carbon nitride (CaO/g-C₃N₄) composite activated under visible light was used to investigate the photocatalytic destruction of CV. The composite material was prepared through a thermal synthesis process and its optical characteristics were analyzed using UV-Vis spectroscopy. Photocatalytic performance tests showed that the CaO/g-C₃N₄ composite achieved 90.38 % degradation of CV within 180 minutes, outperforming pure g-C₃N₄, which reached only 40% degradation under identical conditions. The improved photocatalytic activity was primarily ascribed to more effective charge carrier separation and enhanced dye adsorption due to the presence of CaO. These findings demonstrate the potential of CaO/g-C₃N₄ as an eco-friendly and efficient photocatalyst for visible light-driven wastewater treatment.

Keywords: - Photocatalysis, Crystal Violet, CaO/g-C₃N₄, UV-Vis Spectroscopy, Visible light degradation

1. Introduction

Water pollution caused by industrial discharge containing 1-15% synthetic dyes released in environment has become a pressing global environmental issue [1, 2]. Among these pollutants, triarylmethane dyes such as Crystal Violet (CV) are particularly problematic due to their extensive use in various applications, including textile dyeing, biological staining for Gram-positive bacteria, and as antimicrobial and antifungal agents in veterinary medicine [3]. CV is a cationic dye known for its high toxicity, chemical resilience, and resistance to biodegradation [4, 5].

Even at extremely low concentrations, it poses major risks to human health and aquatic environments due to its mutagenic and carcinogenic qualities [6].

Conventional wastewater treatment methods such as coagulation, flocculation, adsorption, and biological treatments often fall short in effectively removing CV due to its stable aromatic structure and persistence in aquatic systems [7].

In response, As a result, Advanced Oxidation Processes (AOPs) have become more popular as viable substitutes for treating persistent organic pollutants [8]. Among them, heterogeneous photocatalysis is

unique in that it uses reactive oxygen species (ROS) produced by semiconductor photocatalysts under light irradiation to fully mineralize organic dyes into innocuous end products like carbon dioxide (CO₂) and water (H₂O) [9].

Graphitic carbon nitride (g-C₃N₄) is one such material that has attracted interest because of its sensitivity to visible light (bandgap ~2.7 eV), chemical and thermal stability, non-toxic nature, and cost-effective synthesis from precursors like urea or melamine [8]. Graphitic carbon nitride (g-C₃N₄) is one such material that has attracted attention because of its visible light sensitivity (bandgap ~2.7 eV). However, pure g-C₃N₄ has drawbacks like a small number of surface-active sites and fast recombination of photogenerated electron-hole pairs, which limit its overall photocatalytic efficiency [8]. To address these shortcomings, recent studies have explored the fabrication of heterojunction photocatalysts by combining g-C₃N₄ with other functional materials. One such material is calcium oxide (CaO), an inexpensive, alkaline earth metal oxide that offers several advantages as a cocatalyst [2] with high surface area, strong adsorption capacity for cationic dyes like CV via electrostatic interactions and ability to generate hydroxyl radicals (OH) under light exposure.

When integrated with g-C₃N₄, CaO/g-C₃N₄ composites have demonstrated enhanced photocatalytic activity, attributed to efficient charge separation, where CaO serves as an electron acceptor, reducing electron-hole recombination and improved dye adsorption, due to acid-base interactions between CV and the basic CaO surface.

Despite these promising outcomes, the majority of research on CaO/g-C₃N₄ systems has relied on artificial light sources such as xenon lamps, which are energy-intensive and impractical for large-scale applications. In contrast, visible light-driven photocatalysis using natural sunlight presents a more environmentally friendly and economically feasible solution. However, systematic investigations into CV degradation under natural irradiation remain limited.

2. Objectives of this study:

This research aims to develop a simple and efficient thermal synthesis route for CaO/g-C₃N₄ composites, utilizing low-cost, earth-abundant materials to create an effective photocatalyst for wastewater treatment. In this approach, CaO is prepared from hen eggshell, promoting the use of sustainable and bio-derived sources. The study will investigate the composite's optical properties using UV-Vis spectroscopy to assess its light-harvesting capabilities in the visible spectrum. Furthermore, the photocatalytic degradation of crystal violet dye will be evaluated through kinetic and mechanistic studies to understand the degradation process under visible light. A charge transfer pathway will also be proposed based on the composite's photocatalytic performance.

The findings will contribute to sustainable wastewater treatment technologies by leveraging visible light as an energy source and using affordable, renewable materials. This research supports SDG 6 (Clean Water and Sanitation) by offering a potential solution for decentralized wastewater treatment, particularly in resource-limited settings. Additionally, it will provide valuable insights into the synergistic mechanisms between metal oxides and carbon nitrides, enhancing photocatalytic efficiency and contributing to environmentally friendly technologies for pollutant degradation.

The degradation capacity was calculated by using the formula-

$$q_e = \frac{C_o - C_e}{m} \cdot v$$

where m is the sample's weight in grams, v is the dye solution's volume in liters, the starting dye concentration is denoted by C_o (mg/L), the residual dye concentrations at equilibrium by C_e (mg/L), and the adsorption capacity of the semiconductor material by q_e (mg/g).

CV dye percentage degradation was estimated as follows:

$$\text{Degradation efficiency (\%)} = \frac{C_o - C}{C_o} * 100$$

3. Materials and Method

3.1 Materials used

Eggshell, Sodium Hydroxide (NaOH), calcium chloride (CaCl_2), Methyl Orange, Crystal Violet, Urea ($\text{CO}(\text{NH}_2)_2$), Ethanol (EtOH), dye concentration (10, 20, 30, 40, 50, 100) ppm.

3.2 Preparation of CaO

The preparation of calcium oxide (CaO) from eggshells begins with the collection of clean waste hen eggshells. The collected eggshells are first immersed in hot boiling water at 100°C for about 30 minutes. This treatment helps loosen the inner membrane attached to the shell, making it easier to remove manually. After peeling off the membrane the eggshells are thoroughly washed with distilled water to eliminate any remaining impurities, dirt or organic residues. The cleaned shells are then allowed to dry and subsequently placed in a hot air oven at 110°C for one hour to remove any residual moisture content. Complete drying is essential to ensure efficient grinding and calcination in the later stages [9].

After removing the membrane, the eggshells are rinsed thoroughly with distilled water to get rid of any leftover impurities, dirt, or organic matter. Once cleaned, the shells are allowed to air dry and then placed in a hot air oven at 110°C for one hour to eliminate any remaining moisture. Ensuring complete dryness is crucial for effective grinding and calcination in the subsequent steps [9].

After drying, the eggshells are pulverized into a fine powder using a mortar and pestle. The powdered eggshell increases the surface area, facilitating even heat treatment during the calcination process. The finely ground material is then transferred to a silica crucible and positioned inside a muffle furnace. The sample is calcined at 300°C for a specified period to initiate the thermal decomposition process. During calcination the organic matter present in the eggshell powder is removed and the material undergoes structural changes [10]. The resulting calcined powder rich in calcium compounds is collected and stored in an airtight and opaque container for further use and characterization.

3.3 Preparation of g- C_3N_4

Urea was used as the precursor material to create graphitic carbon nitride (g- C_3N_4). Initially, a clean silica crucible was filled with precisely weighed 20 g of urea. To minimize material loss during the heating process, a lid was placed over the crucible. After that, it was heated for two hours at 550°C in a muffle furnace. Graphitic carbon nitride was created as a result of the urea's slow breakdown and a number of chemical alterations. The furnace was turned off when the heating process was finished, and the crucible was left inside the furnace to naturally drop to room temperature [11]. This slow cooling helps in the

proper formation of the material. A yellow-colored solid product was obtained after cooling. To achieve a consistent particle size, the product was meticulously gathered and pounded into a fine powder using a mortar and pestle. The prepared g-C₃N₄ powder was then stored in a clean, airtight container for further characterization and experimental studies.

3.4 Composite formation

The g-C₃N₄/CaO composite was prepared by a simple sonication-assisted mixing method using a 1:1 weight ratio of g-C₃N₄ and CaO. First, a 100 mL beaker with 20 mL of ethanol was filled with 0.1 g of g-C₃N₄. The mixture was then sonicated for 15 minutes to ensure that the g-C₃N₄ particles were well dispersed in the ethanol and formed a uniform suspension. After this, an equal amount of CaO was added to the beaker containing the g-C₃N₄ suspension. The resulting mixture was further sonicated for 45 minutes to promote thorough mixing and improve the interaction between the g-C₃N₄ and CaO particles.

Following sonication, a homogeneous suspension was obtained. The prepared mixture was then transferred to an oven and kept at 368.15 K (95°C) for 24 hours to allow complete evaporation of the ethanol. During this process, the solvent gradually evaporated, leaving behind the g-C₃N₄/CaO composite material [12]. Following drying, a mortar and pestle were used to gently grind the solid product into a fine powder in order to ensure consistency. After that, the produced composite powder was kept in an airtight, clean container for additional analysis and photocatalytic research.

Result and discussion

3.5 Study of dye degradation with contact time effect

Preparation of solution

20 mL of a 50 ppm Crystal Violet dye solution was mixed with 0.025 g of the produced photocatalyst (g-C₃N₄, CaO, or g-C₃N₄/CaO composite) for the photocatalytic degradation investigation. To create adsorption-desorption equilibrium between the dye molecules and the catalyst surface, the mixture was agitated for 30 minutes in the dark using a magnetic stirrer. A UV-visible spectrophotometer was used to measure the solution's initial absorbance following the dark stirring time. After that, the suspension was exposed to visible light for three hours in total. Samples were examined at regular intervals of one hour throughout the radiation period, and the absorbance was determined to track the dye's deterioration. As exposure time increased, a progressive drop in absorbance was seen, suggesting that the photocatalyst had successfully broken down the methyl orange dye [8].

Using g-C₃N₄, CaO, and the g-C₃N₄/CaO composite photocatalysts, (Figure a) illustrates the impact of contact duration on dye degradation [13]. The findings demonstrate that for all catalysts, the degrading efficiency rose as the radiation period increased. Due to the abundance of active sites on the catalyst surface, dye molecules were quickly broken down during the experiment's first phase. The rate of degradation progressively decreased and got closer to equilibrium as the process proceeded.

The composite catalyst exhibited the highest degradation performance compared to pure g-C₃N₄ and CaO, indicating the combined effect of the two materials. The degradation increased steadily up to 180 minutes, where the maximum degradation capacity was achieved. Beyond this point, no noticeable increase in degradation was observed, suggesting that the system had reached equilibrium. The improved

performance of the g-C₃N₄/CaO composite can be attributed to enhanced charge separation and better utilization of visible light, which promoted the photocatalytic degradation of the dye. Overall, the composite catalyst demonstrated superior photocatalytic activity and showed greater efficiency in reducing dye concentration compared to the individual materials.

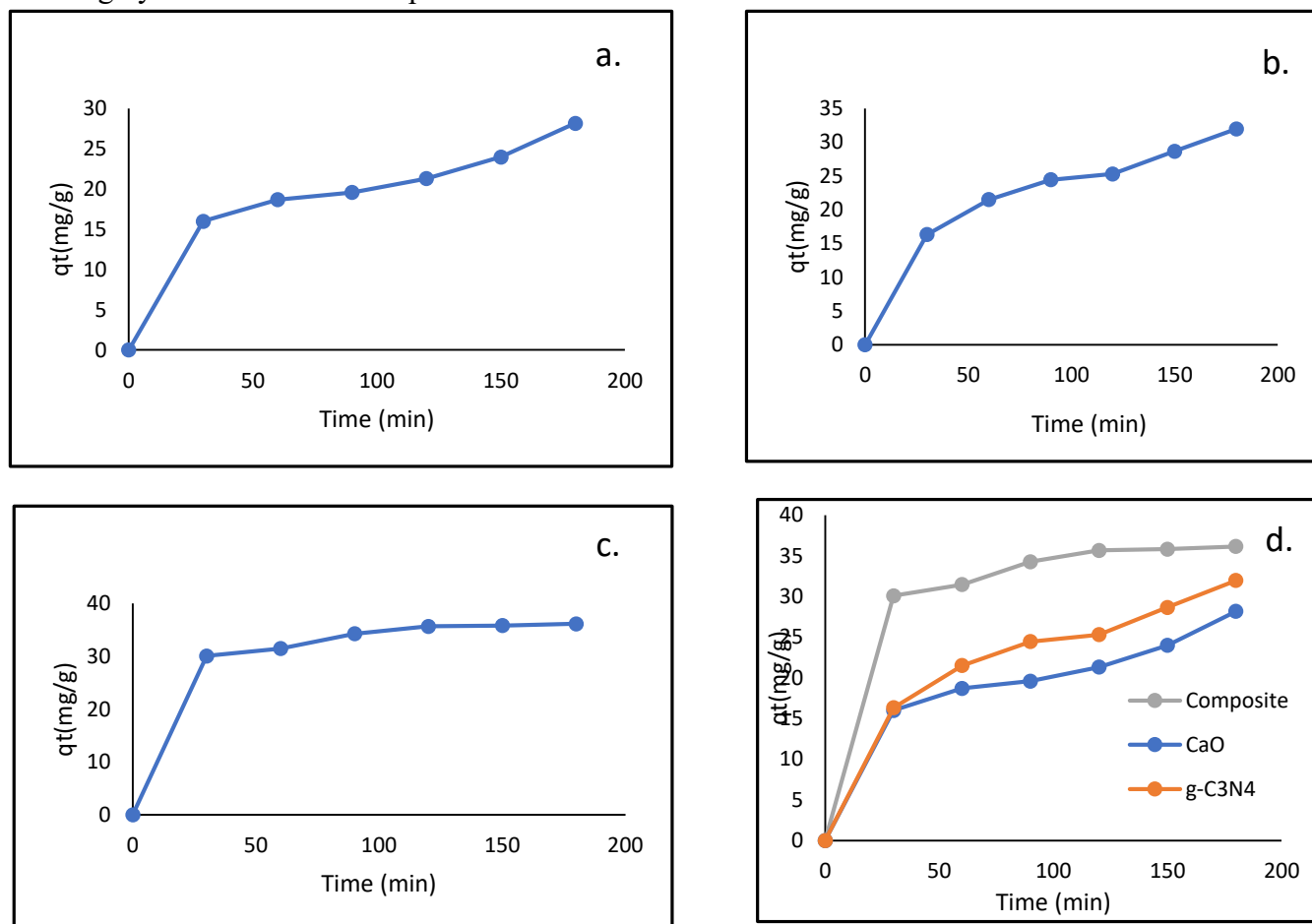


Figure 1: (a) Time study of CV with CaO, (b) Time study of CV with g-C₃N₄, (c) Time study of CV with CaO- g-C₃N₄, (d) Time study comparison CaO, g-C₃N₄, CaO- g-C₃N₄ composite

3.6 EFFECT OF pH STUDIES

A 50 ppm dye solution was made by diluting 25 mL of a 100 ppm stock solution to 50 mL in a standard volumetric flask in order to investigate the impact of pH on the photocatalytic degradation of Crystal Violet (CV) dye. 0.1 M HCl and 0.1 M NaOH solutions were used to bring the pH of the mixture to 2, 4, and 6.

Each dye solution received 0.025 g of the CaO/g-C₃N₄ composite photocatalyst after pH correction. To reach a degradation equilibrium between the dye molecules and the catalyst surface, the resultant suspension was agitated for 30 minutes in the dark using a magnetic stirrer. After then, the solution was exposed to sunshine for three hours. A UV-visible spectrophotometer was used to measure the absorbance at regular intervals of one hour in order to track the degradation of CV dye [20].

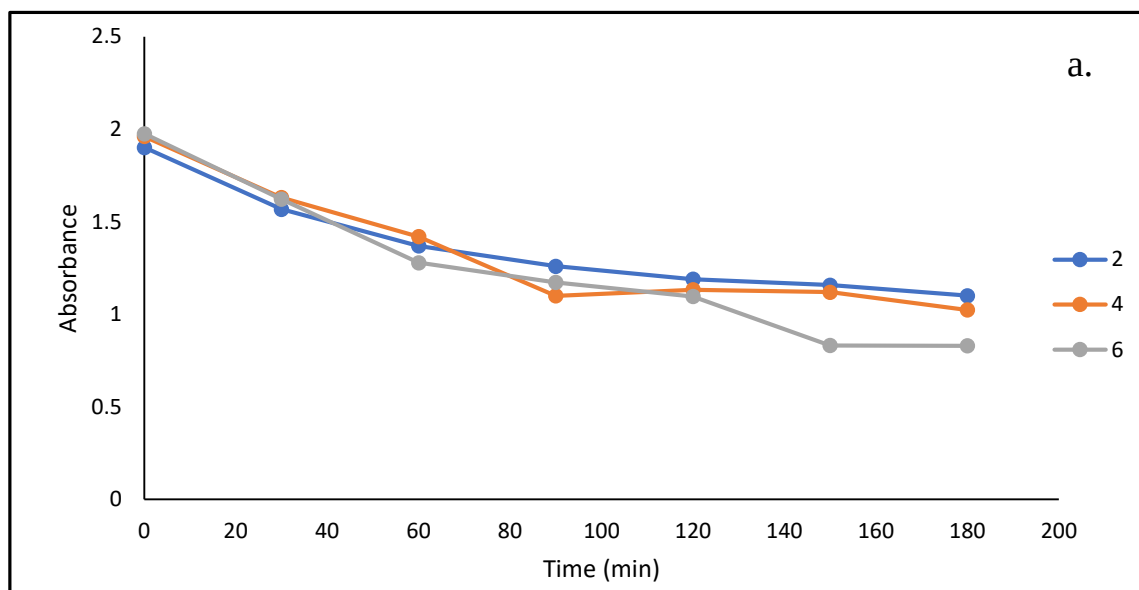
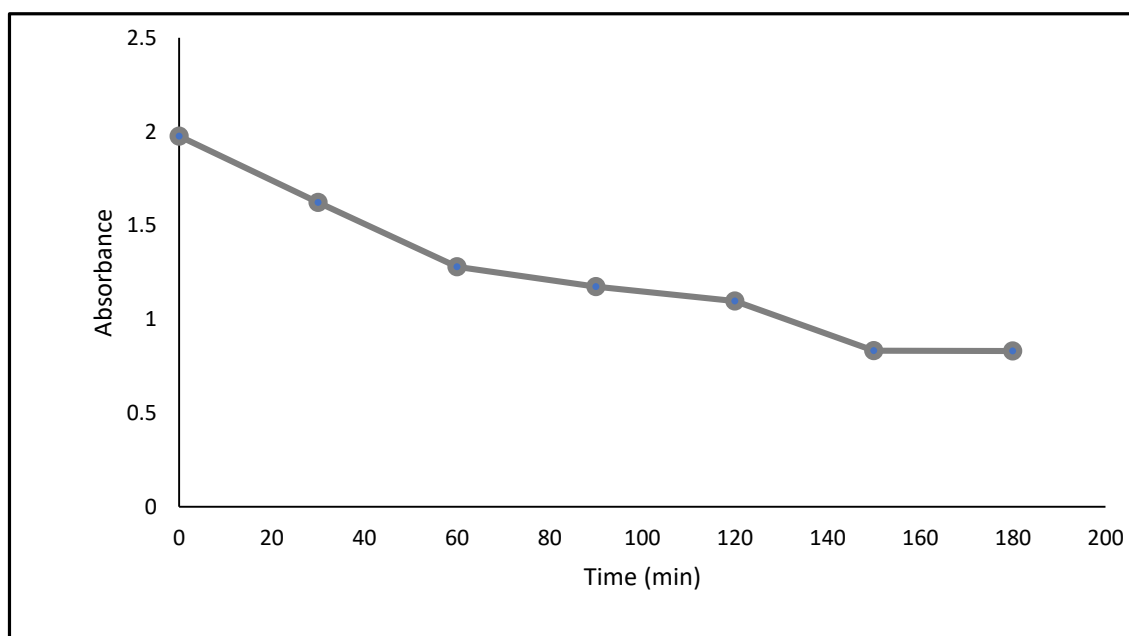
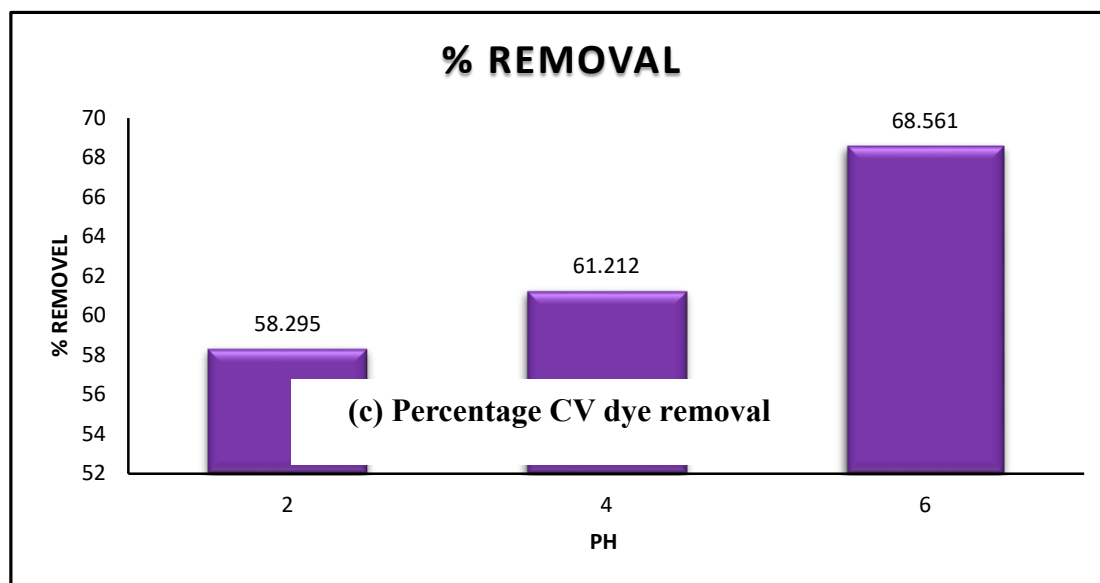


Figure 2: (a) Comparison studies at pH 2, 4 and 6



(b) Study at pH 6



Photocatalytic degradation of Crystal Violet dye was found to depend significantly on the pH of the solution. As the reaction progressed, a gradual decrease in absorbance was observed, indicating degradation of the dye molecules [9].

Among the investigated pH values, the highest degradation efficiency was observed at pH 4 and 6 pH. At these pH levels, the absorbance decreased more rapidly compared to the other pH conditions, showing enhanced photocatalytic activity of the composite.

At pH 2, the degradation was relatively low, and the absorbance remained higher than that observed at pH 4.

EFFECT OF TEMPERATURE

The effect of temperature on the photocatalytic degradation of Crystal Violet using CaO–g-C₃N₄ composite was investigated at 25°C, 35°C, and 45°C. The reaction mixture containing 50 ppm dye solution and 0.025 g of photocatalyst was irradiated under identical conditions, and the degradation was monitored using UV–Visible spectroscopy at $\lambda_{\text{max}} = 600 \text{ nm}$ for a period of up to 240 minutes. It was observed that the degradation efficiency increased with rise in temperature. At higher temperature, enhanced molecular diffusion, increased collision frequency between dye molecules and reactive species, and improved charge carrier separation contributed to the higher degradation rate. Among the studied conditions, 45°C exhibited the highest photocatalytic activity, followed by 35°C and 25°C. This indicates that the reaction kinetics are temperature dependent and follow an accelerated degradation pathway at elevated temperatures [24].

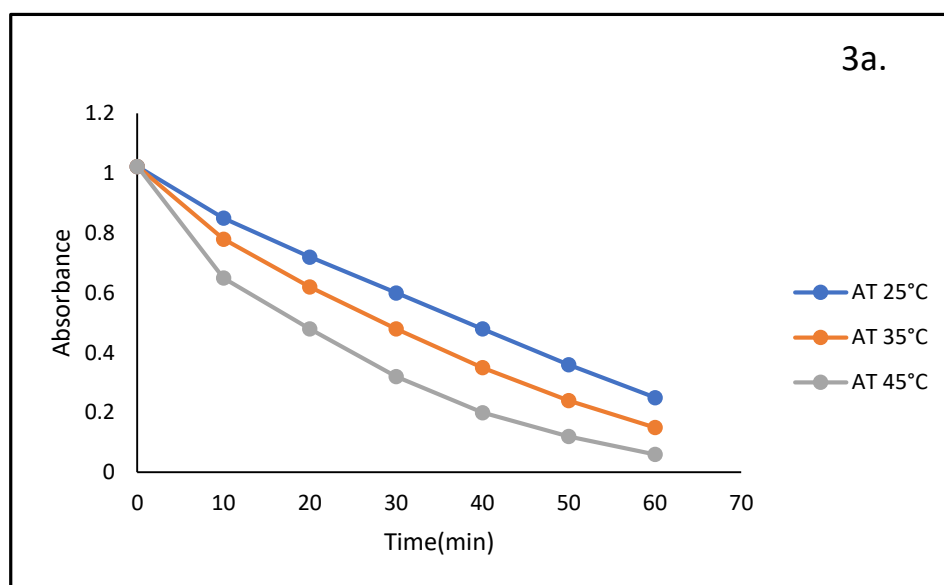


Figure 3: Effect of temperature 25°C, 35°C, 45°C

3.7 EFFECT OF DOSAGE

Using varying concentrations of the synthesized CaO/g-C₃N₄ composite (0.020 g, 0.025 g, and 0.030 g) exposed to natural sunshine for 180 minutes, the impact of catalyst dosage on the photocatalytic degradation of 50 ppm Crystal Violet (CV) was examined. The degradation efficiency was evaluated by monitoring the normalized dye concentration (C/C_0) at different irradiation times. Initially, the value of C/C_0 was 1.7 for all catalyst dosages, indicating the same initial dye concentration. As the irradiation time increased, the C/C_0 value decreased for all samples, confirming the progressive degradation of Crystal Violet.

Among the three catalyst dosages, 0.025 g exhibited the highest photocatalytic activity, with the C/C_0 value decreasing from 1.734 to 0.12 after 180 minutes, corresponding to approximately 95% degradation. This enhanced performance can be attributed to the availability of an optimum number of active sites, efficient absorption of sunlight, and effective generation of electron-hole pairs, which promote the formation of reactive oxygen species responsible for dye degradation. The availability of an ideal number of active sites, excellent sunlight absorption, and efficient electron-hole pair generation all of which encourage the development of reactive oxygen species that cause dye degradation are responsible for this improved performance.

The catalyst dosage of 0.020 g showed comparatively lower degradation efficiency, with the C/C_0 value decreasing from 1.73 to 0.31 (approximately 88% degradation) after 180 minutes. The lower efficiency is mainly due to the insufficient amount of catalyst, resulting in fewer active sites and reduced production of reactive species.

The degradation efficiency significantly declined when the catalyst dosage was increased to 0.030 g; after 180 minutes, the C/C_0 value reached 0.25, or almost 90% degradation. Excessive catalyst loading results in particle agglomeration and raises the suspension's turbidity even though more catalyst offers more active sites. This inhibits the photocatalyst's effective use and decreases sunlight penetration [37].

Consequently, it was discovered that the ideal catalyst dosage for the photocatalytic degradation of Crystal Violet dye under sunlight was 0.025 g of CaO/g-C₃N₄ composite, offering the best degradation efficiency among the catalyst doses examined [25].

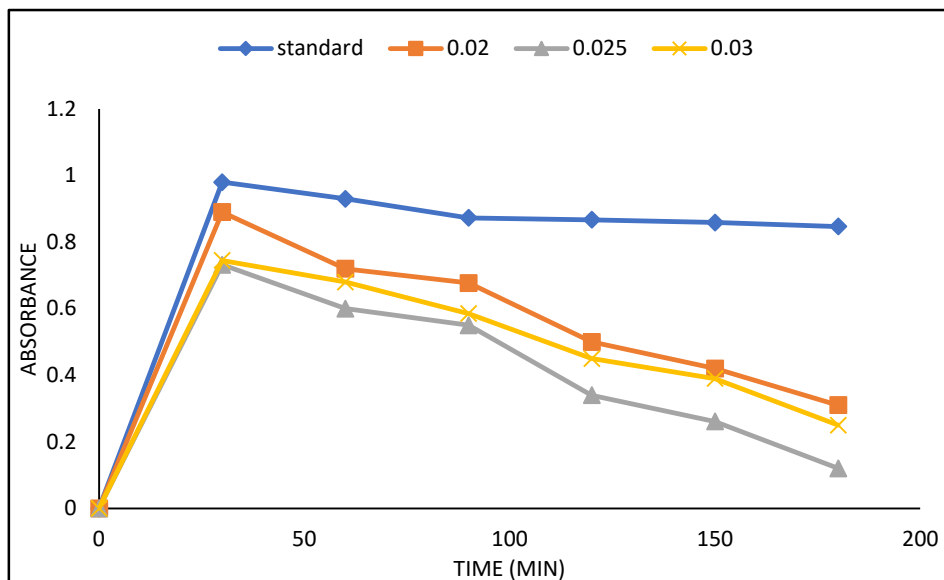


Figure 4: Study of dosage 0.02, 0.025 and 0.03(in gm) with respect to time

Photocatalyst	Dye	Initial Dye Concentration (mg/L)	Catalyst Dosage	Optimum pH	Time (min)	Degradation (%)	Reference
CaO/g-C ₃ N ₄ (Present work)	Crystal Violet	50	0.025 g	6	180	50	Present Study
Au/TiO ₂	Crystal Violet	10	0.5 g/L	6–7	60	>75	[37]
CuO/ α -Fe ₂ O ₃	Methyl Orange	20	1.0 g/L	7	120	88.47	[8]
Eggshell/g-C ₃ N ₄	Congo Red	20	0.5 g/L	7	90	90.5	[9]

Table 1. Photocatalytic performance comparison of various photocatalysts

4 CaO-g-C₃N₄ nanoparticle Characterizations

The textural characteristics of the produced CaO, g-C₃N₄ nanoparticle were examined using TEM micrographs.

Figure 5 shows the TEM images of CaO, g-C₃N₄, and CaO–g-C₃N₄ nanostructures. Sheet-like nanoparticles may be seen in the CaO picture (Figure 5a). In contrast, the g-C₃N₄ image (Figure 5b) reveals layered structures with soft surface sheets typical of graphitic nanostructures [1]. Additionally, TEM images of CaO–g-C₃N₄ taken at different magnifications Figures 5 (a–d) show a relatively random morphology. The CaO–g-C₃N₄ nanoparticle has a two-dimensional nanosheet-like nanoparticle structure. The CaO nanoparticles in the CaO–g-C₃N₄ nanoparticle range in size from 20

to 60 nm on average. There are several self-active sites on the nanoparticle due to the CaO particles' uniform distribution across the g-C₃N₄ surface.

Figure 6 shows the materials' XRD pattern. The (100) and (002) planes are represented by the characteristic diffraction peaks for g-C₃N₄ at 12.92° and 27.64°. The first peak, which corresponds to the distance between the holes in the nitride pores, shows the in-plane packing of trietiazine units with a d-spacing of 0.685 nm. The stacking of C–N aromatic units separated by the aromatic system's interlayer spacing of 0.322 nm is responsible for the stronger peak at 27.64° [2]. In the meantime, the (110), (200), (202), (311), and (222) planes of the cubic phase of CaO are represented by the diffraction peaks at 32.14, 37.25, 53.77, 64.00, and 67.30° [3]. The CaO peaks are accompanied by peaks for Ca(OH)₂ and CaCO₃ at 18.00°, 29.32°, 44.84° and 7.39°, respectively. In addition to fast carbonation and hydrolysis of CaO in the presence of ambient CO₂ and water vapor, the presence of calcite (CaCO₃) and hydroxide peaks indicates incomplete pyrolysis of the precursor.

According to the literature, CaO nanoparticles are highly effective at capturing CO₂ [4]. Overall, the material's XRD pattern (Figure 6) verifies the existence of both g-C₃N₄ and CaO peaks, demonstrating the successful formation of the CaO–g-C₃N₄ nanoparticle.

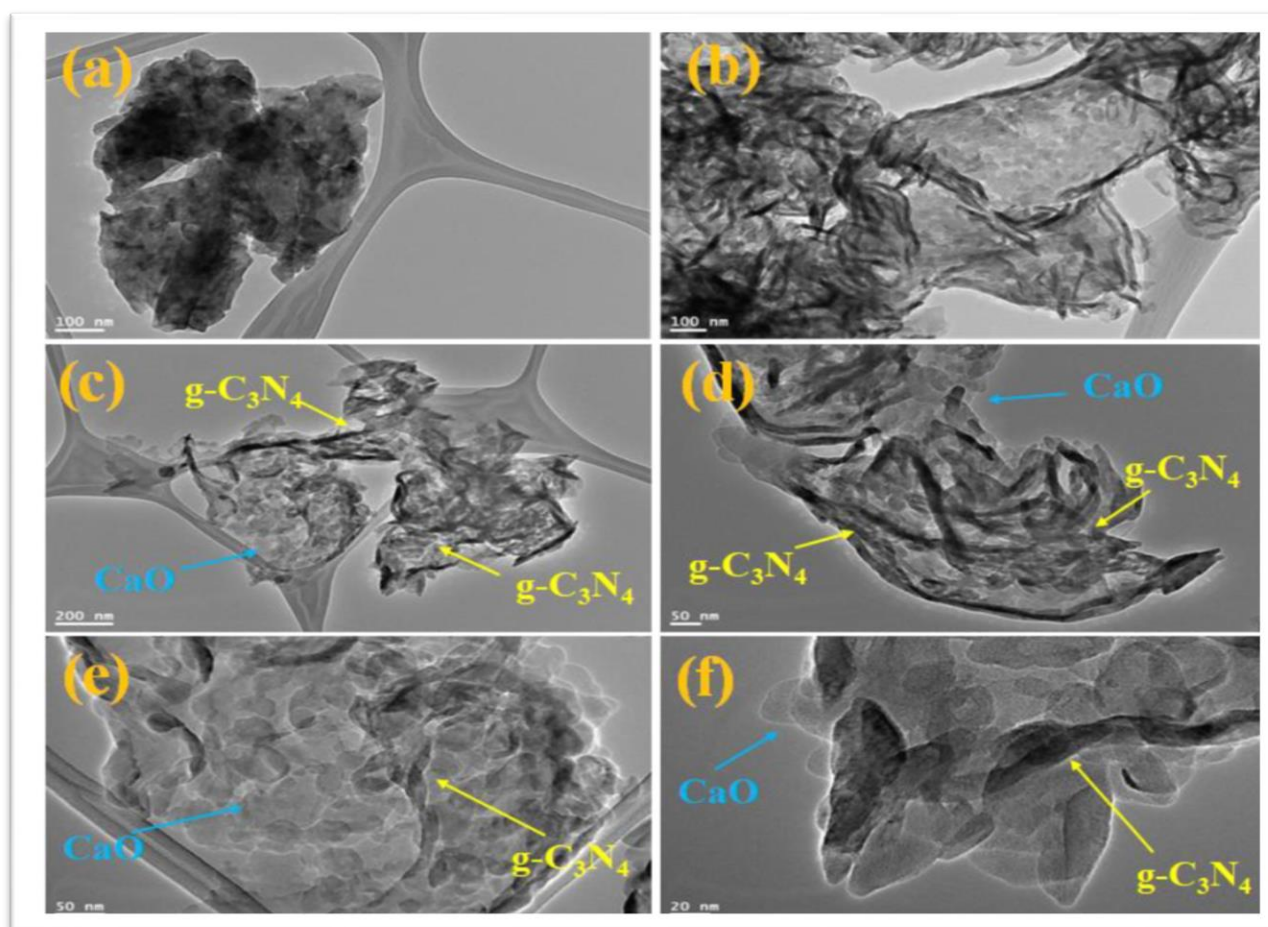


Figure 5. TEM images of (a) CaO, (b) g- C₃N₄, and (c–f) CaO-g- C₃N₄ nanoparticle with different magnifications.

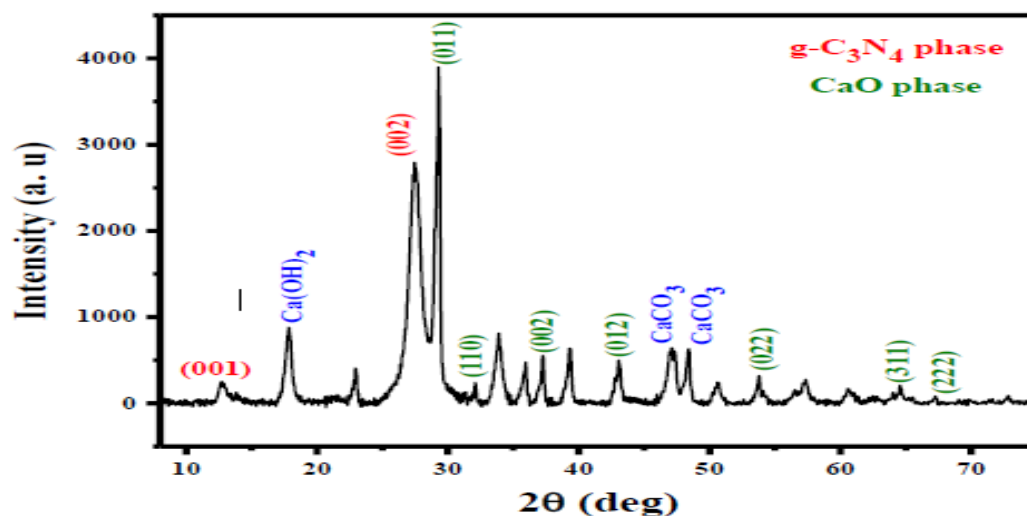


Figure 6. XRD patterns of CaO-g- C₃N₄ nanoparticle.

5 Adsorption Mechanism

FTIR spectroscopy was used to examine the mechanism of Crystal Violet (CV) dye adsorption onto the CaO-g-C₃N₄ composite. The FTIR spectra of the CaO-g-C₃N₄ composite before and after the adsorption of CV dye are shown in Figure 7. The stretching vibrations of O-H and N-H groups are responsible for the broad adsorption band in the region of 3000-3600 cm⁻¹ in the spectra of the pure CaO-g-C₃N₄ composite. The stretching vibration of aromatic C-N bonds is represented by the adsorption peaks at around 1242, 1326, and 1412 cm⁻¹, whereas the C=N stretching vibration of the graphitic carbon nitride framework is represented by the peaks at roughly 1578 and 1640 cm⁻¹. The peak at about 805 cm⁻¹ verifies the presence of Ca-O bonds in the composite, while the distinctive band near 884 cm⁻¹ is linked to the breathing mode of the triazine ring.

The FTIR spectrum showed discernible alterations following the adsorption of crystal violet. A number of the CaO-g-C₃N₄ composite's typical absorption bands moved somewhat, and new bands corresponding to CV dye emerged, showing that the molecules had successfully adsorbed onto the composite surface. The shift in the aromatic C-N, C=N and triazine ring vibration band suggest strong interaction between the conjugated structure of graphitic carbon nitride and the aromatic ring of crystal violet [8].

Additionally, the broad O-H and N-H stretching bands showed minor modifications during adsorption, suggesting the creation of hydrogen bonds between the nitrogen-containing groups in crystal violet molecules and the functional groups of the CaO-g-C₃N₄ composite.

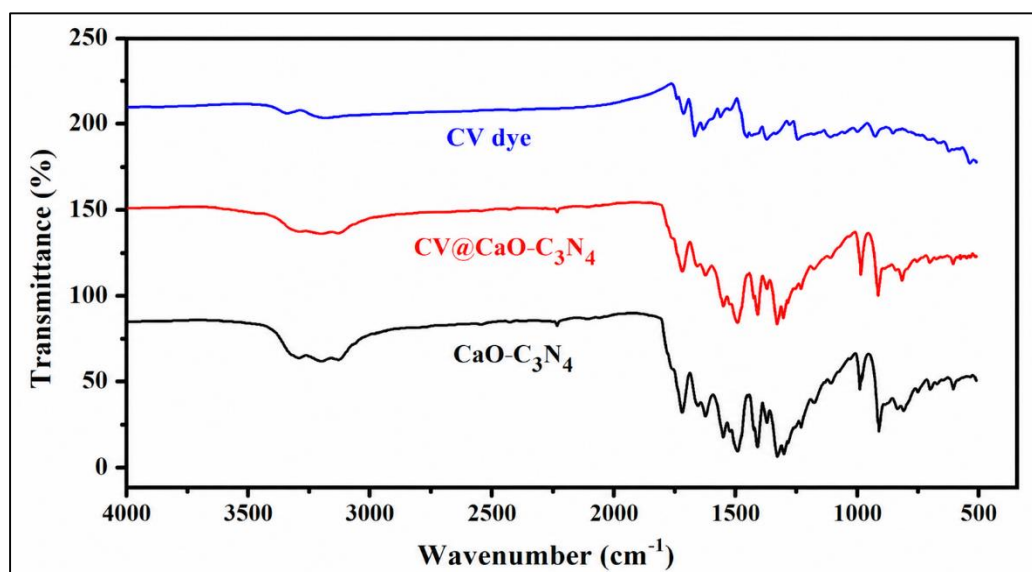
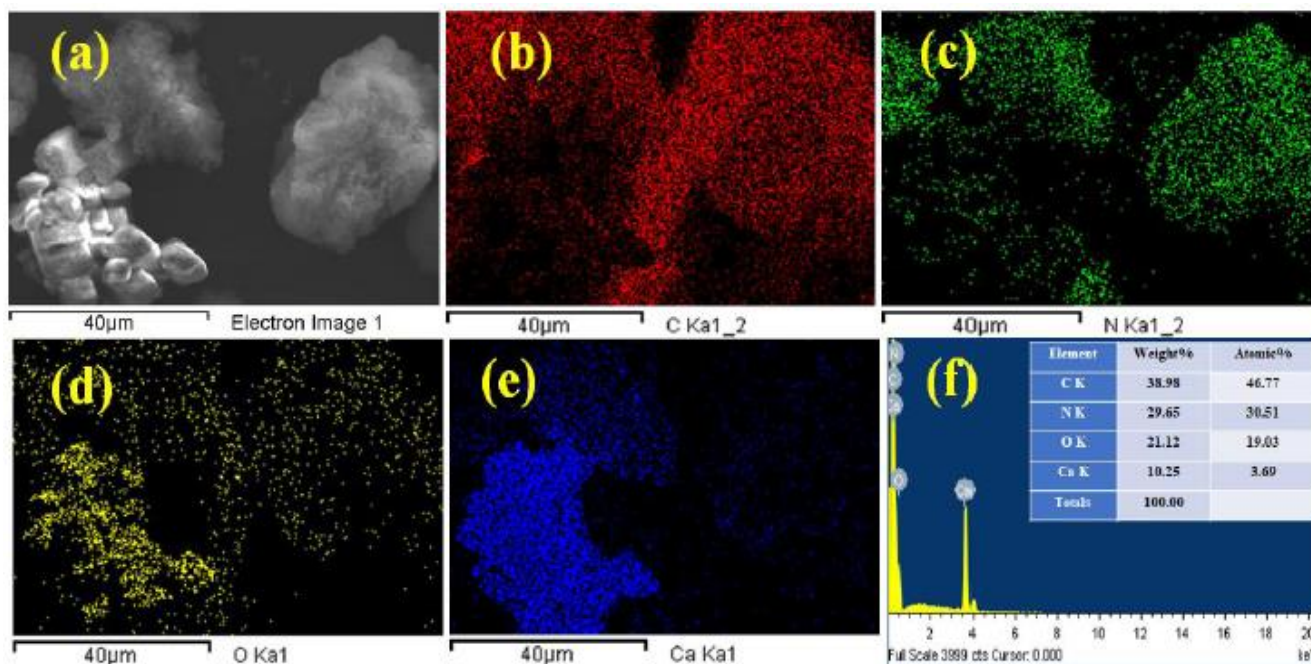


Figure 7. FTIR spectra of CV, CaO-g- C₃N₄ and CaO-g- C₃N₄ @CV

6 Characterization of CaO-g-C₃N₄ Nano catalyst

The elemental mapping analysis of the synthesized CaO-g-C₃N₄ nano catalyst was performed using SEM-EDS to investigate the distribution of the constituent elements. The form of the synthesized composite is depicted in the SEM image (figure 8a), and the distribution of carbon (C), nitrogen (N), oxygen (O), and calcium (Ca) is shown in the corresponding elemental mapping images (figure 8b–e). A higher concentration of the corresponding elements is indicated by the brighter areas shown in the elemental maps. The successful creation of a homogenous CaO-g-C₃N₄ nanocomposite is confirmed by the element's uniform dispersion. Through their distinctive peaks, the EDS spectrum displayed in Figure 8f verifies the presence of carbon, nitrogen, oxygen, and calcium in the produced nano catalyst. The EDS examination yielded an elemental composition of 33.98 weight percent carbon, 29.65 weight percent nitrogen, 21.12 weight percent oxygen, and 10.25 weight percent calcium, indicating that CaO was successfully incorporated into the g-C₃N₄ matrix. The great purity of the synthesized composite is indicated by the lack of any notable impurity peaks. The photocatalytic degradation efficiency of crystal violet dye under visible light irradiation is anticipated to increase due to the uniform distribution of constituent elements, which will improve charge separation and provide more active sites [11].

Figure 8 shows the CaO-g-C₃N₄ nanosorbent's elemental mapping distribution (a–e) and its EDX graph (f).



CaO-g-C₃N₄ nanosorbent's elemental mapping distribution (a–e) and its EDX graph (f).

Photocatalyst		XRD (Crystal Phase)	FTIR (Major Functional Groups)	TEM/SEM Particle Size (nm)	EDX (Major Elements)	Reference
CaO/g-C ₃ N ₄ (Present work)		CaO and g- C ₃ N ₄ phases	C=N, C–N, N–H/O–H, Ca–O	Agglomerated nanosheets/particles	C, N, O, Ca	Present study
CuO/ α -Fe ₂ O ₃		CuO + Hematite	Cu–O, Fe– O	27–49 nm	Cu, Fe, O	[8]
Au/TiO ₂		Anatase + Au	Ti–O	15–30 nm	Au, Ti, O	[37]
MnO ₂ /MnFe ₂ O ₄		Mixed phases	Mn–O, Fe– O	Nanoparticles	Mn, Fe, O	[38]
Eggshell/g- C ₃ N ₄		CaCO ₃ /CaO + g-C ₃ N ₄	Ca–O, C–N	Layered composite	Ca, C, N, O	[9]

Table 2. Characteristics comparison of various photocatalysts

Conclusion:

In this study, a CaO/g-C₃N₄ composite was successfully synthesized using papaya leaf-derived calcium oxide and urea-based g-C₃N₄ through a simple, eco-friendly route. The optical analysis confirmed a redshift in the absorption edge, demonstrating the material's enhanced ability to utilize visible light. This extended absorption and the heterojunction formation between CaO and g-C₃N₄ facilitated efficient charge carrier separation, which in turn improved photocatalytic activity. The composite achieved significant

degradation of Crystal Violet under visible light, clearly outperforming pristine g-C₃N₄, while control experiments confirmed that the process was truly photocatalytic.

Overall, these findings highlight the potential of CaO/g-C₃N₄ composites as cost-effective, sustainable photocatalysts for wastewater treatment. By combining green-synthesized CaO with g-C₃N₄, this work provides a pathway toward environmentally friendly and practical solutions for dye pollution, supporting future clean water technologies.

Author Contributions:

Gaurav Mehta conceptualized the study, carried out the experimental work, analyzed the data, and prepared the original manuscript. Vinayak Kuvalekar assisted in the experimental, work, data collection, and manuscript preparation. Mr. Ramraj Sutar provided technical guidance. Dr. Kiran Upar supervised the overall research, reviewed the manuscript and validated the results. The final manuscript has been read and approved by all authors.

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Conflict of Interest:

Regarding the publishing of this work, the authors state that they have no conflicts of interest. These are appropriate for a research paper and can be edited further if your journal has a specific format or if you need to acknowledge funding or a particular laboratory.

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