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Forensic Examination of Ink Transfer on Folded Documents Using Different Writing Instruments and Paper Types

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Abstract: ***Ink transfer on folded documents is an important phenomenon in forensic document examination, as it may provide valuable information about the sequence of writing, folding, and handling of questioned documents. The present study aims to investigate the transfer of ink impressions on folded papers using different writing instruments and paper types under controlled experimental conditions. Three commonly used writing instruments were selected for the study: Flair Ink Tanker liquid ink fountain pen, Rorito Fanta Flo Hi-Tech ball pen, and Hauser Germany XO gel pen. Writing was performed on three types of paper with varying porosity levels, namely bond paper (low porosity), A4 paper (medium porosity), and notebook paper (high porosity). A standardized paragraph was written on each paper type using the selected pens. The written documents were folded under two different time conditions: immediately after writing and after a delay of five minutes. For each condition, eight samples were prepared. After folding, a constant pressure of approximately 500 g was applied on the folded documents for a period of 24 hours to facilitate possible ink transfer. Following the pressure period, the samples were examined to detect the presence and characteristics of transferred ink. Examination methods included visual examination, stereo microscopic analysis, and ultraviolet (UV) light examination to observe fluorescence or transferred ink impressions. The study evaluates the influence of ink type, paper porosity, and folding time on the extent and visibility of ink transfer. The findings contribute to the understanding of ink behavior on folded documents and may assist forensic document examiners in the interpretation of transfer marks in questioned document cases.***

Keywords: Ink transfer, Folded documents, Forensic document examination, Gel pen ink, Fountain pen ink, Ballpoint pen ink, Paper porosity, Ultraviolet examination.

I. INTRODUCTION

Forensic document examination is a specialized field of forensic science that involves the scientific analysis of questioned or disputed documents. Documents such as letters, agreements, wills, financial records, and anonymous notes often serve as important evidence in criminal and civil investigations. Forensic document examiners analyze various characteristics of documents including handwriting, ink, paper, printing methods, and physical features in order to determine authenticity and detect alterations. One important aspect in document examination is the behavior of ink on paper surfaces. When ink is freshly applied to paper, it may remain on the surface for a certain period before completely drying. If the document is folded or subjected to pressure during this time, the wet ink may come into contact with another part of the paper surface and transfer partially. This phenomenon is known as ink transfer.

Transferred ink may appear as faint mirror images, dots, or smudged impressions of the original writing. The presence or absence of such transferred impressions can provide useful information regarding the sequence of writing and handling of the document. For example, a document folded immediately after writing may show noticeable ink transfer, whereas folding after sufficient drying time may result in minimal or no transfer. Several factors influence the occurrence of ink transfer, including the type of ink used, the drying time of the ink, the porosity and absorbency of paper, and the pressure applied during folding. Studying these factors helps forensic document examiners understand how inks behave under different conditions.

The present study focuses on examining the ink transfer phenomenon in folded documents using different types of pens and paper materials. The influence of the time interval between writing and folding, as well as the effect of applied pressure, is also studied. The transferred impressions are examined through visual observation, stereo microscope analysis, and ultraviolet (UV) light examination to evaluate their characteristics and forensic significance.

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A. Ink and Writing Instruments

Ink is a colored fluid used for writing and printing on paper. In forensic document examination, the study of ink is important because different inks possess distinct chemical and physical properties that influence their behavior on paper surfaces. These properties affect how ink spreads, penetrates into paper fibers, dries, and transfers when the paper is folded. Writing instruments deliver ink onto paper through different mechanisms. The amount of ink deposited on the surface and the thickness of the ink layer may vary depending on the type of pen used. These variations can influence the visibility and extent of ink transfer impressions.

Important characteristics of writing inks include:

- Ink composition – Inks generally contain dyes or pigments dissolved in solvents along with additives that influence color, stability, and flow properties.
- Viscosity – The thickness of ink affects how easily it flows and spreads on paper.
- Drying time – Some inks dry rapidly while others remain wet longer, increasing the possibility of transfer.
- Ink deposition – The amount of ink deposited on paper affects the thickness of the ink layer.
- Interaction with paper fibers – Ink may remain on the surface or penetrate into paper depending on its formulation.

In the present study, three types of writing instruments were used:

- Liquid Ink Pen – Uses liquid ink with relatively slower drying properties.
- Ballpoint Pen – Produces smooth writing with controlled ink flow.
- Gel Pen – Contains gel-based pigment ink which produces darker and thicker lines.

B. Paper Characteristics and Porosity

Paper acts as the medium that receives ink during writing. The structure and composition of paper play an important role in determining how ink behaves after it is applied. When ink comes in contact with paper, it may either remain on the surface or penetrate into the paper fibers depending on the absorbent properties of the paper. One of the most significant factors affecting ink behavior is paper porosity, which refers to the ability of paper to absorb liquids. Papers with lower porosity absorb ink slowly, allowing more ink to remain on the surface. This increases the chances of ink transfer when the paper is folded. In contrast, highly porous papers absorb ink quickly into the fibers, which may reduce the amount of ink available for transfer.

Important paper properties influencing ink transfer include:

- Porosity – Determines the rate of ink absorption into paper fibers.
- Surface texture – Smooth surfaces allow even ink spread while rough surfaces may absorb ink irregularly.
- Absorbency – Highly absorbent papers draw ink rapidly into their fibers.
- Thickness and fiber structure – Influence the penetration and distribution of ink.
- Paper coating or finishing – Some papers have coatings that reduce ink absorption.

Three different types of paper were used in this study:

- Bond Paper (Low Porosity) – Smooth paper with lower absorbency.
- A4 Printing Paper (Medium Porosity) – Standard paper with moderate absorption.
- Notebook Paper (High Porosity) – More absorbent paper commonly used for writing.

C. Ink Transfer in Folded Documents

Ink transfer occurs when freshly written ink comes into contact with another surface before it has completely dried. This situation commonly occurs when a sheet of paper is folded shortly after writing. The wet ink may transfer partially to the opposite side of the paper, producing a faint mirror-like impression of the original writing. The transferred impressions may appear as dots, smudges, or partial mirror images depending on the quantity of ink present and the conditions under which the document was folded. These marks may sometimes be difficult to detect under normal lighting conditions.

Several factors influence the occurrence of ink transfer:

- Time interval between writing and folding – Immediate folding increases transfer.
- Type of ink used – Different inks have different drying characteristics.
- Amount of ink deposited – Greater ink deposition may produce clearer transfer marks.
- Pressure applied during folding – Higher pressure increases surface contact.
- Duration of folded contact – Longer contact time may enhance transfer.

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In forensic document examination, the presence of transferred ink impressions may help determine whether a document was folded shortly after writing or after the ink had dried. Such information can assist forensic experts in reconstructing the sequence of events in document preparation.

D. Methods of Examination

The detection and analysis of ink transfer marks require careful observation using different examination techniques. Some transferred impressions are visible under normal lighting, while others may be faint and require specialized examination methods.

The following techniques were used in this study:

- Visual Examination – Initial observation of documents under normal light to identify visible transferred impressions or smudges.
- Stereo Microscope Examination – Allows magnified observation of ink distribution, paper fibers, and transferred marks.
- Ultraviolet (UV) Light Examination – Certain inks exhibit fluorescence under UV light, making faint transfer impressions easier to detect.

These examination methods help identify and analyze the presence, pattern, and intensity of ink transfer, providing useful information for forensic document analysis.

II. REVIEW OF LITERATURE

The study of ink and its behavior on paper has been a significant area within forensic document examination, particularly in cases involving questioned documents, alterations, and sequence determination. Ink transfer in folded documents is an important yet less explored phenomenon that can provide valuable insights into the handling and timing of document preparation.

1) Brunelle and Crawford (2003) provided a comprehensive overview of forensic ink analysis, emphasizing the role of ink composition, solvent behavior, and drying characteristics in document examination. Their work highlighted that ink behavior varies significantly depending on formulation and environmental conditions.

2) Ellen (1997) discussed the fundamentals of scientific examination of documents, including ink deposition and interaction with paper fibers. He noted that freshly written ink may remain on the surface for a certain period, making it susceptible to transfer under pressure or folding.

3) Hilton (1982), in his classic work on questioned documents, explained that ink transfer can occur when documents are folded before complete drying, producing mirror images or offset impressions. He emphasized its importance in determining the sequence of events.

4) Harrison (1958) highlighted the role of paper characteristics in ink absorption, stating that porosity and surface texture directly influence how ink spreads and dries, which in turn affects transfer behavior.

5) Cantu (1987) studied the differentiation of inks using chromatographic techniques and noted that ink composition (dye vs pigment-based) significantly affects drying time and surface retention, influencing transfer potential.

6) Aginsky (1996) introduced methods for determining the relative age of ballpoint inks and emphasized solvent evaporation patterns, which are directly related to ink drying and transfer possibilities.

7) Lyter (1988) explored ink examination using ultraviolet and infrared techniques, demonstrating that certain inks exhibit fluorescence under UV light, aiding in the detection of faint or transferred impressions.

8) Kelly and Lindblom (2006) discussed the importance of non-destructive techniques in document examination, including UV light and microscopy, for detecting alterations and latent ink traces.

9) Bugler, Buchner, and Dallmayer (2008) examined ink dating techniques and solvent loss, concluding that incomplete drying stages are critical periods where ink is most vulnerable to transfer.

10) Weyermann et al. (2007) investigated the aging of ballpoint inks and found that environmental conditions such as temperature and humidity influence drying rate and ink stability.

11) Brunelle (2009) emphasized the use of stereomicroscopy in document examination to study ink distribution, penetration, and surface characteristics, which are essential for identifying transfer patterns.

12) Ellen (2005) further elaborated on physical matching and transfer evidence in documents, stating that pressure and contact duration significantly affect the quality and visibility of transferred impressions.

13) Harris (2013) discussed the role of UV light in forensic investigations, highlighting its effectiveness in revealing invisible or weak ink traces that are not detectable under normal lighting.

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14) Jones (2015) examined paper–ink interactions and concluded that low porosity papers tend to retain ink on the surface longer, increasing the likelihood of transfer when folded early.
15) Smith and O'Hara (2012) studied the effect of writing pressure and concluded that higher pressure increases ink deposition, which may enhance transfer visibility.
16) Lociciro et al. (2004) explored ink analysis using spectroscopic techniques and emphasized that ink composition influences its physical behavior, including drying and transfer characteristics.
17) Weyermann and Spengler (2005) highlighted that gel inks and liquid inks behave differently compared to ballpoint inks due to differences in viscosity and solvent content.
18) Daéid (2012) in her forensic handbook emphasized the importance of combining multiple examination techniques such as visual inspection, microscopy, and UV analysis for reliable results.
19) Ellen and Day (2010) discussed document handling evidence and noted that folding, pressure, and environmental exposure can leave trace patterns that assist in reconstructing events.
20) Recent studies (2018–2022) in forensic document examination have focused on non-destructive analytical techniques, highlighting the growing importance of UV imaging and microscopic analysis in detecting subtle ink transfer phenomena.

From the reviewed literature, it is evident that while extensive research has been conducted on ink composition, ink dating, and document examination techniques, limited studies specifically address ink transfer in folded documents under controlled conditions. Most existing work discusses ink drying and interaction with paper but does not systematically analyze the combined effects of pen type, paper porosity, folding time, and applied pressure.

Therefore, the present study aims to bridge this gap by experimentally investigating ink transfer using different writing instruments and paper types, along with controlled timing and pressure conditions. The study further incorporates visual, stereomicroscopic, and ultraviolet examination techniques to provide a comprehensive understanding of ink transfer behavior and its forensic significance.

III. AIM AND OBJECTIVE

A. *Aim*

The aim of the present study is to examine the phenomenon of ink transfer in folded documents using different types of writing instruments and paper substrates. The study also aims to evaluate how the time interval between writing and folding, as well as applied pressure, influence the occurrence and visibility of ink transfer marks. The transferred impressions are analyzed using visual examination, stereo microscope observation, and ultraviolet (UV) light examination to understand their characteristics and forensic significance.

B. *Objectives of the Study*

The main objectives of the study are:

- To study the transfer characteristics of different writing inks used in common writing instruments.
- To examine the effect of paper porosity on the occurrence of ink transfer in folded documents.
- To evaluate the influence of time interval between writing and folding on the formation of transferred ink impressions.
- To analyze the effect of applied pressure during folding on ink transfer.
- To detect and examine transferred ink impressions using visual observation, stereo microscope, and ultraviolet light examination.

To understand the forensic significance of ink transfer marks in determining the sequence of events in questioned document.

IV. METHODOLOGY

A. *Materials And Instruments*

The materials and instruments used in the present study were selected to examine the transfer of ink impressions in folded documents under controlled experimental conditions. Different writing instruments and paper types were used in order to observe the influence of ink composition and paper porosity on ink transfer behavior.

1) *Writing Instruments*

The following three writing instruments were used for the experiment:

- Liquid Ink Pen – A liquid ink pen that produces smooth writing and generally takes longer to dry.
- Ballpoint Pen – A smooth-flowing pen designed for controlled ink delivery and moderate drying characteristics.
- Gel Pen – A gel-based pen containing pigment ink which produces darker and thicker writing lines.

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2) Paper Types

Three different types of paper with varying porosity levels were selected for the study:

- Bond Paper (Low Porosity) – Smooth surface with lower absorbency.
- A4 Printing Paper (Medium Porosity) – Standard printing paper with moderate ink absorption.
- Notebook Paper (High Porosity) – Highly absorbent paper commonly used in notebooks.

3) Instruments Used for Examination

The following instruments were used to examine the transferred ink impressions:

- Stereo Microscope – Used for magnified observation of ink patterns and transferred impressions.
- Ultraviolet (UV) Light Source – Used to detect fluorescent or faint ink impressions that may not be visible under normal light.

B. Sample Selection

Samples were selected to represent commonly used writing instruments and paper types in everyday writing situations. The selected pens included liquid ink, standard writing ink, and gel-based ink to observe their different drying and transfer characteristics. Similarly, paper samples with varying absorbency and porosity were selected to evaluate how paper structure influences ink transfer when the document is folded.

C. Methodology

The methodology involved controlled preparation of paper samples, writing with selected pens, folding the samples at different time intervals, and examining the resulting ink transfer impressions.

D. Sample Collection

S. No.	Pen Type	Ink Type	Paper type	Porosity Level	Number of Samples
1	Ballpoint pen	Standard ink	Bond paper	Low	8
2	Ballpoint pen	Standard ink	A4 paper	Medium	8
3	Ballpoint pen	Standard ink	Notebook	High	8
4	Gel pen	Gel ink	Bond paper	Low	8
5	Gel pen	Gel ink	A4 paper	Medium	8
6	Gel pen	Gel ink	Notebook	High	8
7	Ink pen	Liquid ink	Bond paper	Low	8
8	Ink pen	Liquid ink	A4 paper	Medium	8
9	Ink pen	Liquid ink	Notebook	High	8

Table 4.1: The samples used in the experiment

E. Sample Preparation

1) Paper sheets of each selected type were cut into uniform sizes.
2) A standardized text sample was written on each sheet using the selected pens.
3) Care was taken to maintain uniform writing pressure and similar writing patterns for all samples.
4) Multiple samples were prepared for each pen and paper combination to ensure consistency.

E. Examination Procedure

The prepared samples were subjected to folding and pressure conditions to observe the transfer of ink impressions.

1) After writing the text, the paper samples were folded so that the written surface came into contact with the opposite surface of the paper.
2) Two timing conditions were followed:
    - Immediately after writing
    - After 5 minutes of writing
3) A weight of approximately 500 g was placed on the folded papers to apply uniform pressure.

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4) The samples were kept under pressure for 24 hours.
5) After 24 hours, the papers were unfolded carefully.
6) The samples were then examined using visual observation, stereo microscope, and ultraviolet light.

F. *Parameters Assessed*

Parameter	Description
Visibility of Transfer	Whether transferred ink marks were visible to the naked eye
Intensity of Transfer	Degree of clarity or darkness of transferred impressions
Pattern of Transfer	Presence of mirror image, dots, or smudges
Effect of Paper Type	Influence of paper porosity on transfer visibility
Effect of Pen Type	Difference in transfer behavior of various inks
Fluorescence under UV	Presence or absence of fluorescence in transferred ink marks

Table 4.2: The parameters were evaluated during the examination of ink transfer impressions

V. RESULTS AND DESCUSSIONS

The present study was conducted to evaluate the behavior of different writing inks (ball pen, gel pen, and liquid ink pen) on various paper types (bond, A4, and notebook paper) using visible examination, time-based transfer analysis, microscopic examination, and ultraviolet (UV) analysis. The results highlight how ink composition, viscosity, and paper absorbency influence transfer patterns, penetration, and visibility.

A. *Ink Transfer Observation (Immediate Folding – 0 sec)*

Pen Type	Paper Type	Visibility of Transfer	Pattern of Transfer
Ball pen	Bond	Low to negligible	Discontinuous, pressure-based imprint
Ball pen	A4	Low	Faint, uneven transfer
Ball pen	Notebook	Moderate	Slightly visible, broken pattern
Gel pen	Bond	Low	Pressure-based imprint
Gel pen	A4	Moderate to high	Dotted ink transfer
Gel pen	Notebook	High	Faint mirror impression
Liquid Ink pen	Bond	Low	No Transfer
Liquid Ink pen	A4	Moderate	Faint
Liquid Ink pen	Notebook	Moderate	Diffused and slightly feathered

Table 5.1: Ink transfer observation (0 sec)

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Figure 5.1: Visible Ink Transfer Showing on the A4 paper by Gel pen



Figure 5.2: Visible Ink Transfer Showing on the Notebook Paper by Gel pen

The figure shows visible ink transfer on A4 paper using a gel pen under immediate folding conditions. The transfer appears clear, continuous, and well-defined, indicating high ink fluidity and surface availability. Slight diffusion at the edges suggests partial absorption into paper fibers.

B. Ink Transfer Observation (After 5 Minutes)

Pen Type	Paper Type	Visibility of Transfer	Pattern of Transfer
Ball pen	Bond	Negligible	No significant transfer
Ball pen	A4	Very low	Discontinuous, barely visible
Ball pen	Notebook	Low	Faint imprint
Gel pen	Bond	Moderate	Slightly reduced intensity
Gel pen	A4	Moderate	Less uniform, mild fading
Gel pen	Notebook	Moderate	Reduced thickness
Liquid Ink pen	Bond	Low to moderate	Reduced spreading
Liquid Ink pen	A4	Moderate	Slightly faded but visible
Liquid Ink pen	Notebook	Moderate	Diffused and lighter

Table 5.2: Ink transfer observation (5 min)

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After a delay of 5 minutes, ink transfer decreased significantly across all pen types. Ball pen ink showed almost no transfer due to rapid drying and oil-based composition. Gel and liquid inks exhibited reduced but still noticeable transfer, indicating slower drying and higher moisture retention. This demonstrates the importance of time interval in forensic transfer evidence.

C. Microscopic Examination

Pen Type	Paper Type	Microscopic Appearance	Pattern Observed
Ball pen	Bond	Surface deposition with minimal penetration	Sharp edges, no spreading
Ball pen	A4	Slight penetration	Irregular stroke edges
Ball pen	Notebook	Moderate penetration	Broken, pressure-dependent pattern
Gel pen	Bond	Uniform layer on surface	Smooth, continuous
Gel pen	A4	Moderate penetration	Slight diffusion into fibers
Gel pen	Notebook	Deep penetration	Feathering and spreading
Liquid Ink pen	Bond	Penetration into fibers	Slight spreading
Liquid Ink pen	A4	Moderate to deep penetration	Continuous but diffused
Liquid Ink pen	Notebook	Extensive penetration	Feathered, highly diffused

Table 5.3: Microscopic examination result

Microscopic examination shows that ink behavior varies with pen type and paper porosity. Ball pen ink remains mostly on the surface with minimal penetration, while gel and liquid inks show increasing penetration and diffusion. Higher porosity papers like notebook paper exhibit more spreading and feathering, whereas bond paper shows sharper and more defined strokes. These differences help in identifying ink type and paper characteristics in forensic analysis.

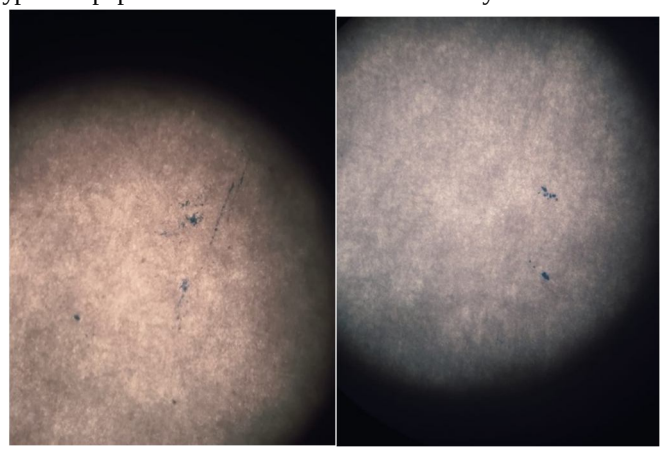


Figure 5.3: Microscopic Result are Shown on A4 Paper + Gel Pen

The microscopic image of gel pen ink on A4 paper shows moderate penetration of ink into paper fibers with relatively smooth and continuous stroke formation. Slight diffusion can be observed along the edges of the strokes, indicating partial absorption into the paper structure. The ink distribution appears uniform, suggesting controlled flow and moderate interaction with the paper surface.

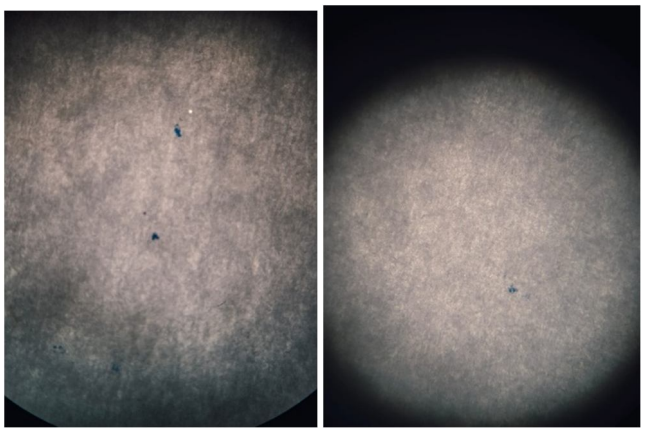


Figure 5.4: Microscopic Result are Shown on Notebook paper + Gel Pen

The microscopic image of gel pen ink on notebook paper exhibits deep penetration and significant spreading of ink within the paper fibers. The stroke edges appear irregular and feathered, reflecting high absorbency of the paper. This results in a diffused and less defined pattern, which is characteristic of highly porous paper surfaces.

D. Ultraviolet (UV) Examination

Pen Type	Paper Type	Long UV 365 nm	Short UV 265 nm	Fluorescence Colour	Observation
Ball pen	Bond	No significant fluorescence	No significant fluorescence	None (bluish background due to UV source)	Ink appears dark; no enhancement
Ball pen	A4	No significant fluorescence	No significant fluorescence	None	Similar behavior; no differentiation
Ball pen	Notebook	No significant fluorescence	No significant fluorescence	None	Ink remains non-fluorescent
Gel pen	Bond	Slight fluorescence	Mild fluorescence	Faint bluish/whitish	Slight enhancement of strokes
Gel pen	A4	Moderate fluorescence	Mild fluorescence	Pale bluish	Better visibility than ball pen
Gel pen	Notebook	Moderate fluorescence	Moderate fluorescence	Bluish-white	Diffused glow due to absorption
Liquid Ink pen	Bond	Mild fluorescence	Slight fluorescence	Pale bluish	Partial enhancement
Liquid Ink pen	A4	Moderate fluorescence	Mild fluorescence	Light blue	Clear but diffused
Liquid Ink pen	Notebook	Moderate fluorescence	Moderate fluorescence	Bluish	Spread with background glow

Table 5.4: UV examination result

UV examination shows that fluorescence depends on ink type and paper properties. Ball pen ink does not exhibit fluorescence and appears dark under both UV wavelengths. Gel and liquid inks show slight to moderate fluorescence, improving visibility in some cases. Higher porosity papers like notebook paper show more diffused glow, while smoother papers provide clearer stroke visibility. UV analysis is therefore useful for selected inks but not universally effective.

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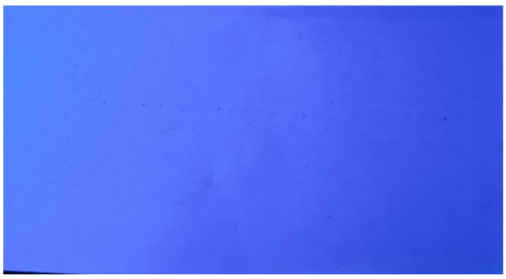


Figure 5.5: Dotted Strokes Are Visible in A4 Paper by Gel Pen

Dotted stroke patterns are visible under UV light, indicating partial ink transfer. The fluorescence enhances faint ink residues, making discontinuous patterns more detectable.

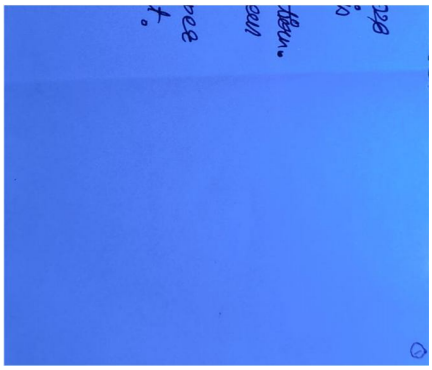


Figure 5.6: Strokes Are Visible of Gel Pen on the Notebook Paper

Ink strokes appear more diffused and spread due to high paper absorbency. UV light highlights the overall stroke pattern, though edges are less defined.

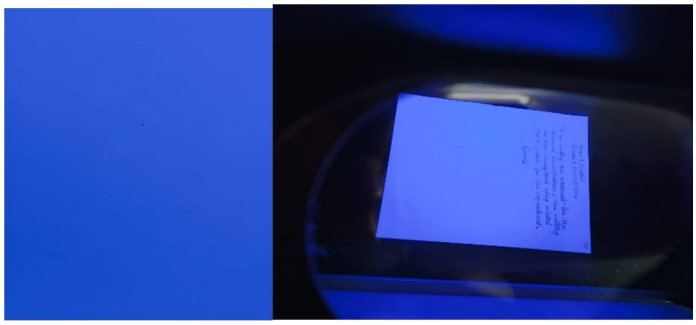


Figure 5.7: Ink pen Partial Mirror Image Are Visible on A4 paper

A partial mirror image of the writing is observed, indicating ink transfer before complete drying. UV illumination enhances the visibility of this transferred impression.



Figure 5.8: Dots Are Found on Notebook Paper by Ink Pen

Scattered dots are visible under UV light, representing fragmented ink transfer. The porous nature of the paper causes diffusion, resulting in irregular dot-like patterns.

E. Comparative Analysis

Examination Method	Result Sensitivity	Key Observation
Visual Examination	Moderate	Visible transfer on A4 paper by gel pen
Microscopic Examination	High	Reveals penetration, stroke pattern, fiber interaction
UV Examination	Variable	Effective only for certain inks (gel/ink), limited for ball pen

Table 5.5: Comparison of Three Methods used for Examination

Comparative analysis indicates that microscopic examination is the most sensitive method, providing detailed information about ink penetration and structure. Visual examination offers moderate detection of transfer, while UV examination is selective and mainly effective for gel and liquid inks.

F. Graphical representation

To better understand the comparative behavior of different inks, a graphical representation was prepared based on four key parameters: ink transfer immediately after writing (0 sec), ink transfer after 5 minutes, microscopic penetration into paper fibers, and ultraviolet (UV) response. The analysis shows that gel pen and liquid ink pen exhibit higher ink transfer immediately after writing, due to their fluid and water-based nature, which allows more ink to remain on the paper surface. In contrast, ball pen ink shows comparatively lower transfer, as it is oil-based and dries faster. After a delay of 5 minutes, a significant reduction in ink transfer is observed for all pen types. However, gel and liquid inks still show moderate transfer, whereas ball pen ink shows negligible transfer, indicating rapid drying and reduced surface availability. Microscopic examination reveals that liquid ink pen demonstrates the highest penetration into paper fibers, followed by gel pen, while ball pen ink largely remains on the surface with minimal penetration. This difference is mainly due to variations in viscosity and solvent composition. Under ultraviolet examination, ball pen ink shows no significant fluorescence, appearing dark due to UV absorption. On the other hand, gel and liquid ink pens show mild to moderate fluorescence, which helps in their detection under UV light. Overall, the graph clearly indicates that ink type significantly influences transfer behavior, penetration, and UV response, which are important parameters in forensic document examination.

Graph Data

Parameter	Ball Pen	Gel Pen	Liquid Ink Pen
Ink Transfer (0 sec)	1	8	5
Ink Transfer (5 min)	0	3	1
Microscopic Penetration	2	7	5
UV Response	1	6	3

Scale: 0 = No effect, 10 = Maximum effect

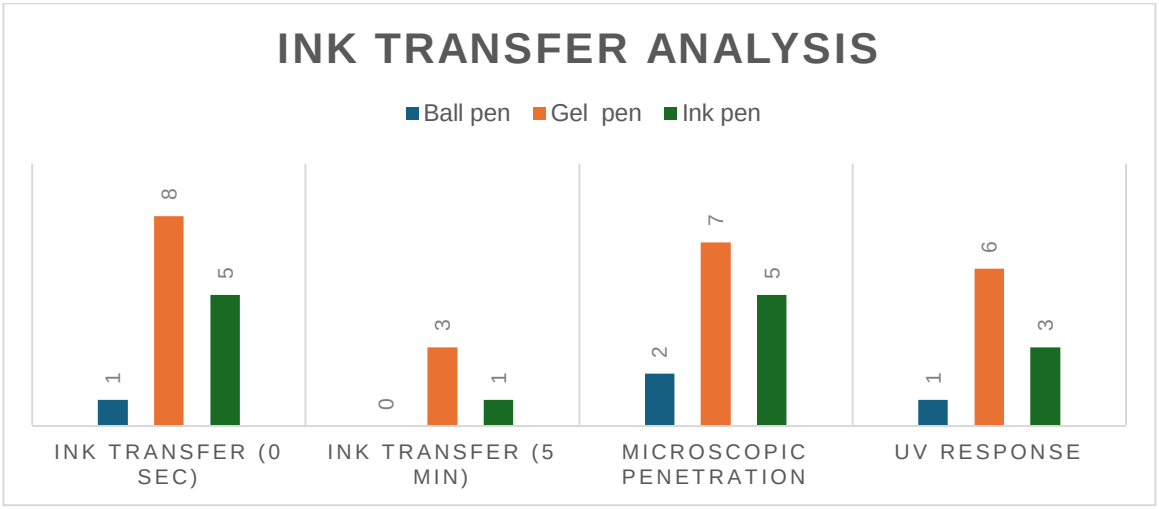


Figure 5.9: Comparative analysis of ink behavior across different pen types

The graph illustrates the comparative performance of ball pen, gel pen, and liquid ink pen across four parameters: immediate ink transfer, delayed transfer, microscopic penetration, and UV response. Gel and liquid ink pens show higher values in transfer and penetration due to their fluid composition, while ball pen demonstrates minimal transfer and negligible UV response due to its oil-based nature. This comparison highlights the importance of ink composition in forensic document examination.

Discussion:

This study demonstrates that both ink composition and paper characteristics play a critical role in forensic document examination.

Ink-Based Differences

Gel and liquid ink pens showed higher transfer, deeper penetration, and partial fluorescence, which can be attributed to their water-based composition. In contrast, ball pen ink exhibited minimal transfer and no fluorescence due to its oil-based and viscous nature.

Effect of Paper Type

Notebook paper showed maximum absorption and diffusion, while bond paper restricted penetration, acting as a relatively controlled surface. This confirms that paper porosity directly affects forensic interpretation.

Time Factor in Transfer

The reduction in transfer after 5 minutes indicates that drying time is crucial in transfer evidence analysis. Immediate transfer may be misleading if time delay is not considered.

Reliability of Techniques

Microscopic examination proved to be the most reliable method, revealing details not visible to the naked eye. UV examination, while useful, showed limited applicability for ball pen inks, emphasizing the need for combined approaches.

Forensic Significance

The findings highlight that no single technique is sufficient. A combination of visual, microscopic, and UV methods is essential for accurate interpretation. These observations are particularly valuable in cases involving document alteration, sequence of writing, and source comparison.

VI. CONCLUSION

The present study systematically evaluated the behavior of different writing inks—ball pen, gel pen, and liquid ink pen—on various paper types using visible examination, time-dependent transfer analysis, stereomicroscopic observation, and ultraviolet (UV) examination. The findings clearly demonstrate that both ink composition and paper characteristics significantly influence ink transfer, penetration, and detectability.

Ball pen ink exhibited minimal transfer and negligible fluorescence under both long-wave (365 nm) and short-wave (265 nm) UV light, primarily due to its oil-based composition and rapid drying nature. In contrast, gel and liquid ink pens showed comparatively higher transfer, greater penetration into paper fibers, and mild fluorescence, indicating their water-based composition and slower drying behavior.

The study also highlights the importance of paper type, where bond paper showed controlled ink deposition with minimal spreading, while A4 and notebook papers demonstrated increased absorption and diffusion due to higher porosity. Microscopic examination revealed significant differences in stroke characteristics, including edge definition, ink penetration, and fiber interaction, which are crucial for forensic document analysis. Time-based observations confirmed that ink transfer decreases substantially after drying, emphasizing that timing plays a critical role in transfer evidence interpretation. Immediate folding resulted in maximum transfer, whereas delayed contact reduced visibility across all ink types. Ultraviolet examination proved to be a supportive but limited technique, particularly for ball pen inks, which showed no significant fluorescence. However, gel and liquid inks exhibited mild fluorescence, aiding in differentiation under UV conditions.

Overall, this study establishes that a combined analytical approach—integrating visual, microscopic, and UV methods—is essential for reliable forensic document examination. It also reinforces that even basic laboratory techniques, when applied systematically, can yield meaningful results, especially in resource-limited forensic settings.

A. Scope For Further Enhancement

While the present study provides important insights into ink behavior and document examination, several areas can be further explored to enhance accuracy and forensic applicability:

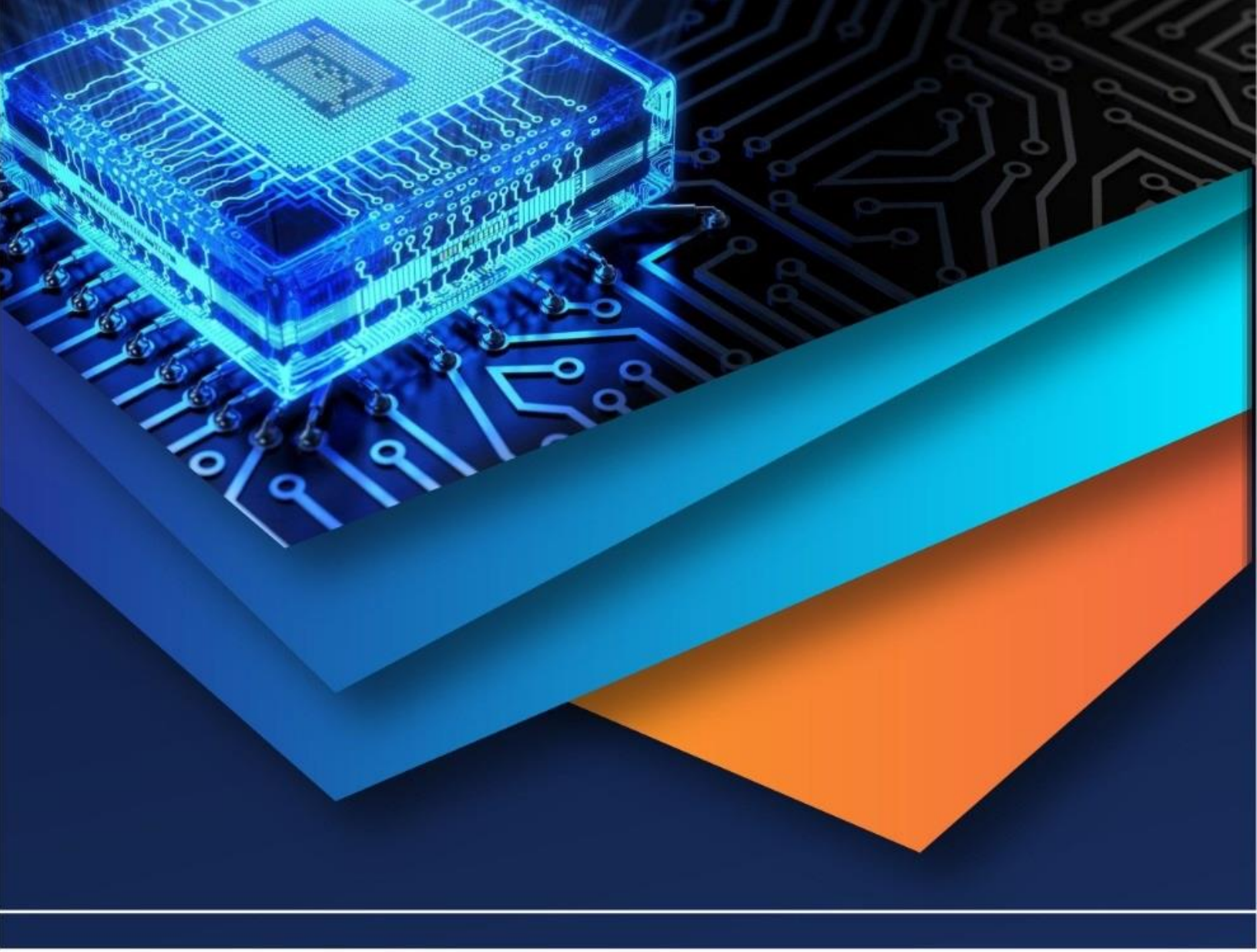
1) Quantitative Image Analysis: Future studies can incorporate digital image analysis software to measure parameters such as ink spread, penetration depth, and line thickness, reducing subjectivity and improving reproducibility.

2) Expanded Ink and Paper Variety: Including a wider range of writing instruments (marker pens, fountain pens, hybrid inks) and paper types (coated, recycled, glossy) would improve the generalizability of findings.
3) Time-Series Studies: Detailed time-based studies (e.g., 0 sec, 5 min, 1 hour, 24 hours) can provide deeper insights into ink drying, transfer reduction, and aging characteristics relevant to forensic timelines.
4) Advanced Spectroscopic Techniques: Techniques such as Thin Layer Chromatography (TLC), Fourier Transform Infrared (FTIR) spectroscopy, and Raman spectroscopy can be used to analyze chemical composition and differentiate inks at a molecular level.
5) High-Resolution Microscopy: The use of scanning electron microscopy (SEM) or digital microscopy can provide enhanced visualization of ink-fiber interaction and microstructural details.
6) Environmental Impact Studies: Studying the effect of environmental factors such as humidity, temperature, and light exposure on ink stability and fluorescence can simulate real-case forensic conditions.
7) Artificial Intelligence Integration: AI-based image processing tools can be developed to automatically identify ink patterns, classify pen types, and detect subtle differences beyond human observation.
8) Standardization of Examination Protocols: Developing standardized guidelines for ink and document examination would improve consistency, reliability, and acceptance of results in forensic and legal contexts.

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