DECIPHERMENT OF INVISIBLE INK THROUGH DIFFERENT TECHNIQUES

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APPROVAL SHEET

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CANDIDATE'S DECLARATION

I hereby certify that the work which is being presented in the thesis, entitled **"DECIPHERMENT OF INVISIBLE INK THROUGH DIFFERENT TECHNIQUES"** in fulfillment of the requirements for the award of the degree of Doctor of Philosophy in Forensic Science in School of Basic and Applied Sciences and submitted in Galgotias University, Greater Noida is an authentic record of my own work carried out during a period from September 2018 to September 2022 under the supervision of **Dr. Rajeev Kumar** and co-supervisors **Dr. Suneet Kumar** and **Dr. Sudhir Kumar**.

The matter embodied in this thesis has not been submitted by me for the award of any other degree of this or any other University/Institute.

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This is to certify that the above statement made by the candidate is correct to the best of our knowledge.

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ABSTRACT

Invisible inks have become the latest and the most common tool used by the criminals for committing different type of white collar crimes. They are used for committing crimes related to documents like wills, cheque, property papers, deeds, financial documents, bills, contracts and many other important documents. These invisible inks have become the most common tool for document related forgeries. Different brands are available in the markets which provide invisible ink pens, the most common and the oldest brand is Pilot. Hamley hamster, Cello, Vikson and many other brands also manufacture these invisible ink pens. Thermochromic erasable ink and disappearing ink are widely used for the same purpose.

Thermochromic erasable ink is the one which depends on the temperature. They are also known as thermal ink. This thermal erasable ink disappears at high temperature and again become visible when low temperature is provided. The thermal ink pens come with a rubber erasure fitted either on the top or bottom of the pen which can be used to generate heat by friction in order to remove the ink lines. This process of rubbing the ink lines with the rubber erasure disturbs the fibers of the paper. The degree of disturbance depends on the type of paper used and also on pressure used during the rubbing process.

On the other hand disappearing ink behave as a pH indicator, it slowly disappears when exposed to acidic environment like atmospheric carbon dioxide. It can be restored easily by providing basic environment. Thymolphthalein is the most common pH indicator used to prepare blue colour disappearing ink. Phenolphthalein on the other hand is commonly used to prepare red colour disappearing ink. Its transition range is around 9.3-10.5. Thymolphthalein is usually a colourless powder or solution but it instantly turns blue when it is mixed with sodium hydroxide and upon reaction with the atmospheric carbon dioxide, its pH decreases below 10.5 and it again turns colourless. The fading of ink is depending on this colour change. On reaction of NaOH in the ink with the carbon dioxide in the air gave the residue of sodium carbonate, which is not visible to the naked eye on paper but gave fluorescence under the UV light. The concentration of pH indicators like thymolphthalein and phenolphthalein can affect the

vanishing time and also the stability of disappearing ink. Disappearing ink is used in for different purposes like it is used for marking in textile industry, dance classes, sports, for paintings. It is also used in academic institution to prepare papers. But now a day, it is widely used by the criminals for committing crimes. Disappearing ink and erasable ink pens are easily available at the local markets and online platform in different colours.

This present research explains the different types of inks, different properties of invisible inks, nature of invisible inks and basic composition of invisible ink. Effect and examination of invisible ink on three different types of papers are studied in this research. The types of papers used are copier paper also commonly known as the printer paper, bond paper and glossy paper. All three varieties of paper used differ in their properties and compositions. This study also explains different types of techniques that can be used by the document examiners and other law enforcement agencies to restore or decipher these invisible writings. Examination through easily available refrigerator to decipher thermochromic erasable ink writings is found to be very useful, cost-effective and non-destructive technique. Chemical examination techniques like sodium hydroxide method and iodine fuming method are reliable and give good result but at the same time they are destructive in nature. U.V. cabinet which is easily available in most of the labs is very cost-effective and reliable technique for deciphering invisible writings. Deciphering invisible writings with the help of oblique light and Photoshop software is the new and successful technique discussed in this research. Video Spectral Comparator (VSC) is found to be the best tool to decipher invisible writings on different variety of papers. It is very important to spread awareness about different types of invisible inks available in the market.

Keywords: Ink analysis, disappearing ink, questioned document, forensic science, invisible ink, erasable ink.

DEDICATED TO MY PARENTS

MR. BHARAT SINGH

&

MRS. VEENA SINGH

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1	Das Anamika, Suneet Kumar	A brief review on invisible ink: its various types and examination methods	Journal of university of Shanghai for Science and Technology	Published	Scopus
2	Das Anamika, Suneet Kumar, Sayeed Ahmed	Effect of Thermochromic ink on different types of papers	Indian journal of Forensic Medicine and Pathology	Published	Scopus
3	Das Anamika, Rajeev Kumar	Pen pressure: An important tool in online signature verification	Forensic Agora- 2019	Published	UGC-Care
4	Das Anamika, Suneet Kumar, Sudhir Kumar, Sayeed Ahmed	Visualization of Thermochromic ink & Disappearing ink writings through various techniques on different paper surfaces	International Journal of Medical Toxicology and Legal Medicine	Published	Scopus
5	Das Anamika Suneet Kumar, Sudhir Kumar, Sayeed Ahmed	Study of pen pressure points to differentiate between genuine and forged documents	International Journal of Medical Toxicology and Legal Medicine	Communicated	Scopus
6	Das Anamika Suneet Kumar, Sayeed Ahmed, Rajeev Kumar	Deciphering Overwriting Alterations done by using Invisible Ink on different paper types	Journal of the Canadian Society of Forensic Science	Communicated	Scopus

LIST OF ABBREVIATIONS

Abbreviation	Full Form
ASTM	American Society for Testing and Materials
VSC	Video Spectral Comparator
MLI	Multiple Laser Images
OVI	Optically Variable Ink
OCR	Optical Character Recognition
TLC	Thin Layer Chromatography
GLC	Gas Liquid Chromatography
ATF	Bureau of Alcohol, Tobacco and Firearms
HPTLC	High Performance Thin Layer Chromatography
APF	Axial Pen Force
CZE-ESI/MS	Capillary Zone Electrophoresis with Electrospray Mass Spectrometric detection
MECC-DAD	Micellar Electrophoretic Capillary Chromatography with UV/Vis Diode Array Detection
ESI-MS	Electrospray Mass Spectrometry
LDI-MS	Laser Desorption Ionization Mass Spectrometry
MSP	Micro-spectrometry
FLE	Filtered Light Examination
PGMEA	Propylene Glycol Mono-methyl Ether Acetate
FTIR	Fourier Transform Infra-Red
IR	Infra-Red
DRIFTS	Diffuse Reflectance Infra-red Fourier Transform Spectroscopy
RS	Random Spectroscopy

SEM	Scanning Electron Microscopy
MS-GC	Mass Spectrometry & Gas Chromatography
GC	Gas Chromatography
PE	2- Phenoxyethanol
LC-MS	Liquid Chromatography- Mass Spectrometry
SEM/EDX	Scanning Electron Microscopy with Energy Dispersive X-ray Spectroscopy
MALDI	Matrix Assisted Laser Desorption/Ionization
LDI	Laser Desorption/Ionization
MS	Mass Spectroscopy
SPME	Solid Phase Micro Extraction
GC-MSD	Gas Chromatograph Equipped with a Mass Selective Detector
TLC-IA	Imaging Analysis Software for studying Thin Layer Chromatograms
RGB	Red Green Blue
TOF-SIMS	Time of Flight Secondary Ion Mass Spectrometry
SERS	Surface Enhanced Raman Scattering
HS-SPME GC/MS	Head Space-Solid Phase Micro Extraction Gas Chromatography/Mass Spectrometry
RT	Random Transform
SVM	Support Vector Machine
FD	Fractual Dimension
PCA	Principal Component Analysis
HSI	Hyperspectral Imaging
ESDA	Electro-Static Detection Apparatus
DTW	Dynamic Time Warping

UV-Vis	Ultraviolet-Visible
VIS	Visible Spectroscopy
FLE	Filtered Light Examination
U.S.S.S	United States Secret Service
GC-MS	Gas Chromatography-Mass Spectrometry
NIST	National Institute of Standards and Technology
S/N	Signal to Noise ratio
V	Visible
PV	Partially Visible
NV	Not Visible
SM	Smudging Visible

CHAPTER - 1

INTRODUCTION

1.1 Background of questioned Documents:

Any writing, symbol, or picture on any kind of surface like paper, table, wall, floor, fabric etc. written with ink, paint or any other tool is considered as a document. If the authenticity of that document is in question then it becomes Questioned document.

In today's fast developing world, criminals or forgers are becoming even more smarter and more advanced with each passing day. Crimes or forgeries that involve any type of document comes under the category of white collar crimes. White collar crimes include different types of crimes like bank frauds, credit or debit card frauds, counterfeiting currency notes, forgery of different types of documents including will, cheque, deeds, property papers, suicide notes, threatening letters etc. These types of cases are handled by forensic questioned document examiner (1-2).

Different types of questioned document related cases are:

- Alterations are done in will by adding a numeral, letter or word by the forger.
- Tampered documents are of various types like charred or partially charred documents, documents which are altered from its original form, indented documents, documents on which invisible ink is used, teared or torned documents, erasing of documents by chemical or physical erasure, obliteration of documents, insertion in documents, addition of something on documents (3).
- Questioned documents where ink is used as the means of forgery. In some cases invisible ink is used to do alterations in a document, age of ink need to be examined, two or more types of inks are used etc.
- In some cases the writer itself tries to manipulate their own writing by disguising, such writings are called as disguised handwritings. The writer itself tries to hide their original writing by making an attempt to hide their individual characteristics and some foreign characteristic to it (4).
- Document examiners also play a vital role in kidnapping cases where handwritten ransom notes are sometimes found. In some cases more than one ransom notes are received by the kidnapper which can be analysed to determine how many persons

are involved or to determine whether the notes are written by one or more individuals.

- Bank fraud cases also encountered in large numbers, cheque are altered in some cases by adding a letter, digit or word.
- Forged handwriting/signatures are the most common type of forged documents encountered. The document examiners need to analyse these forged handwriting/signatures by looking into the individual and class characteristics. In some cases forgery may be of different types like traced forgery, implantation forgery, etc. It is very important for the experts of document to have deep knowledge about this field and all types of forgeries (5).
- Handwritten suicide notes are found at the scene of crime in most of the suicide cases. The document examiner need to examine whether it is written by the victim itself or not. This helps the investigating agencies in solving the whole case.
- Counterfeiting currency notes is the major issue faced by investigating agencies in today's world. The examiner needs to analyse and examine these cases with more attention. It is very important for the examiner to have complete and detailed knowledge of all the security features found on currency notes in order to accurately distinguish original and duplicate one. There are number of security features found on currency notes which the examiner can analyse, for example signature of governor, optical fibre strip found at the centre of note, micro-printing and many more.
- In arson cases, charred and partially charred documents are commonly encountered by the document examiner. These documents might be very useful in further investigation. It is required to decipher the information written on these charred documents. The document examiner must fulfil this requirement by examining these charred documents. It is very difficult to even handle these charred documents as they are very fragile.
- Printed documents are also tampered by the criminals with the intend to again some benefit. The forgers sometimes adds some information or delete some information from the original document. The examination of forged printed documents is not

easy but the document examiners can do this task by examining certain factors in order to establish the authenticity of the document.

- Photocopied documents are also forged by the criminals and just like printed documents, examination of photocopied documents is also difficult. In this case, it is important to understand what is asked. Sometimes the question is to examine whether the submitted document is original or not, sometimes it is to examine whether it is the first copy or second copy of the original document. The examiner analyse the ink type used for the preparation of original photocopied document in order to determine the source of the original document. For example, if toner ink is used by the original document then it indicates that the source of that particular document is a laser printer and it might be the case of inkjet printer. After this that particular printer has to be found by further examination of the document for drum defects, marks of defective metal chip, trash marks, glass platen defects, gooping of ink, alignment of letters or words, formation of letters etc. Ink examination can also be done in these cases like type of ink, age of ink, composition of ink etc.
- Rubber stamp forgery is very common in legal matters. The examiner must first compare the rubber stamps with each other and after that with the stamped result. Different features related to rubber stamps are examined like type of rubber as well as the weariness of rubber is also examined, type of printing done on the rubber stamp is also examined, careful examination is done to identify any type of tear or anomaly, ink is also examined and compared of original with the question in order to identify its identity. ASTME-2289-03 is the standard guide which can be should be followed by the examiner in the examination of rubber stamps.
- Questioned document examiners also deal with the cases related to credit card or debit card frauds.
- Wax seals present on legal documents are also forged. In order to examine such documents the examiner must examine features like quality of wax, type of wax, size of the seal, numerals or words written on it, process of printing, information written on the seal, any type of wear or tear or defect present on the original seal.

- Disappearing ink cases are also becoming common now a day. Criminals are using this ink to defraud people. Many cases are encountered by the document examiners which involves use of disappearing ink. The examiner must carefully examine such cases in order to identify which part has been altered. Careful ink examination is required in such cases (6).
- Cases of notary seals are also accompanied by the document examiners. Analysis or examination of these notary seals is somewhat similar to the examination of rubber stamps. In both the cases, the document examiner first compare and analyse the quality of seal, marks of any wear and tear, the impressions the seal made on different document, manufacturing defects if any, etc.

Questioned document examiner examines all different types of document related cases mentioned above. Besides the ones' mentioned above there are many other cases of different types which are daily dealt by the examiner. Such cases in which the document examiner receive an anonymous letter which is handwritten, the examination of these type of case is really very difficult because there will be no comparable material like admitted handwriting samples. The forensic document examiner solves these cases by finding a way to analyse such cases.

Passport forgeries are also very common and examined by the questioned document examiner. Analysis and examination of passports related crimes are done similar to counterfeited currency notes. Examiner in these cases examine the document for intaglio printing, fluorescence writing, examination of ink, micro-printing, security threads, different patterns and security features found on passports where examined. Results of examination of genuine and forged passports are compared to arrive at a conclusion.

Every day comes with new types of cases for questioned document examiners. Cases with unique questioned samples comes which required new and advanced methods or instruments to solve them because every case is unique and never same.

Analysis of ink is mostly performed to answer following three questions:

1) whether one or more type of ink is used in the suspected document;
2) to determine the source of ink;
3) When the ink is placed on the document (7).

It is important for the examiner to have deep and complete knowledge about the chemistry of different types of ink and also about the different techniques used in the examination of ink.

Examination of questioned document involves many different aspects that are need to be analysed by the forensic document examiner. Some of the factors that are required to be analysed the examiner are examination of paper and its types, examination of ink used and its types and different characteristics and writing characteristics of the writer. Different variety of inks is encountered time to time from either chemical synthesis or natural sources. Additional challenges come when unusual characteristics of inks are used in execution. The traditional methods are not enough to examine such cases. It is required to develop new and innovative techniques and methods for the examination of documents (8).

1.2 History of Ink:

Ink is a solution that is used to produce an image, or a text or any kind of design. This solution is used for writing or drawing purpose by using a instrument which can be a pen, quill, brush, reed pen etc. These inks are also used for printing in different thicker forms.

Ink had been discovered around the since the ancient times for fulfilling different purposes like writing, painting, printing etc. In 26^{th} century BC it was used for drawing as well as writing purpose in Ancient Egypt.

Chinese were considered to be the first who discovered ink probably by mixing up of different materials like animals, plant dyes and mineral inks. Bamboo sticks or brushes were used as a writing instrument to apply inks. At that time various different natural materials were used to prepare inks like coloured juices, extract of substances form

animal, plants and minerals which include indigo, sepia, pokeberries, alizarin and cochineal. Iron salt solution mixed with tanning extract was also used for writing purpose from centuries. This is considered to be the base of modern blue-black inks.

Block printing was developed by the Chinese in the 11th century with more gelatinous and heavier inks. In Medieval Europe, parchment was used in place of papers by scribes. Due to greasy nature of parchment papers, carbon inks are not able to perform normally on them. To overcome this various different experiments were performed and investigated to produce an ink which can perform better on parchment paper. Finally iron gall inks were discovered by mixing iron salt with tannic acid, they are available to be used in 9th century. It was very interesting to see that this iron gall ink was transparent initially but when it is applied to the parchment paper, the salt and acid present in it react chemically and leave a residue of dark colour which penetrate the parchment paper and left markings which are permanent. In order to improve longevity and flow of ink Gum Arabic was added as a thickening agent.

In 1856, William Henry Perkin in England issued the first patent related to making of coloured ink. In the mid-1800s aniline ammonia based inks began to appear. These inks are less corrosive to pen as well as to paper and they can be converted to an unprecedented of colours. These inks can smear in moist condition so they are left in light to fade. The mineral oil used in the preparation of these inks were replaced with varnish. Varnishes of different stiffness were developed to be used for inks. The inks which are oil based dry quickly and penetrate newsprint rapidly.

In the beginning of 20th century, making of inks had become a very complicated task. Today ball-point pens and fountains pens are easily available in the market.

A famous German celebrity Johannes Gutenberg. He was well known as an inventor of letterpress with movable letters, also invented a special type of oil based ink.

In 1890, Neumann and Schlutigg, a German chemist invented a special recipe to prepare iron gall ink. In 1912, this recipe of iron gall ink was adopted by the state of Massachusetts and thus it reached the gold standard in all official U.S. documents.

1.3 Basic composition of Ink:

All inks basically contain following substances:

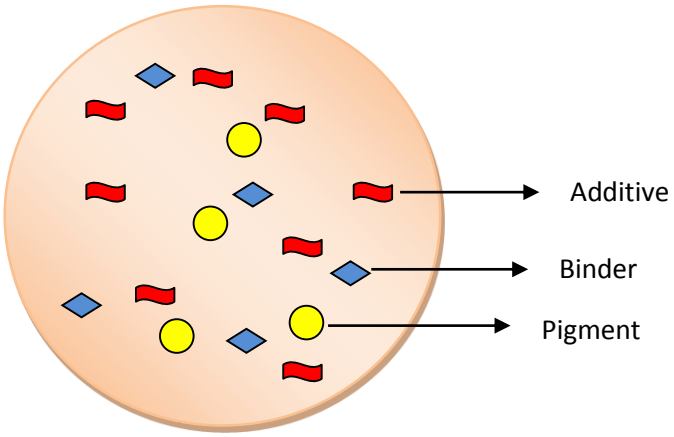


Figure 1.1: Basic composition of ink

1. Pigment

The colour of ink comes from two substance either dye or pigments. Dyes are water soluble whereas pigments are insoluble in water. Pigment itself is a kind of a dye which the pen delivers to the paper or in case of printed document to the printed paper. Pigments are dry, powdery substances or tiny coloured particles like certain minerals. They are mixed with water to leave various colours. Charcoal or soot was first used as a pigmenting agent for ink. Charcoal is cheap and easily available pigment.

2. Carrier or Vehicle

A carrier is a solution in which pigment or dye is dissolved and this solution is transfer to the medium. There are different types of carrier solution like water-based and oil based. Oil based vessels work better with pigments binding the medium. Vegetable oil, Animal fat can be used to prepare oil based vessels.

3. Additive

Additives are added to the ink to give certain basic qualities and unique characteristics to the ink. For example, waxes can be added to the ink to give durability and toughness, driers are added to make ink quick drying, fillers like clay

are also added, glycerides are added to increase the smoothness of ink so that it glides easily and smoothly on paper, etc.

4. Binder

Binders are the one which holds the pigment particles together and helps in binding it to the support. It basically carries the pigments of the ink to the substrate. It also gives print properties like drying, transfer and setting characteristics. The binders are also responsible for providing properties like strength, solvent resistance, surface appearance, rub resistance, gloss and flexibility. One can categorized ink binders into different types based on resin and polymer types: hydrocarbon resin, acrylics, modified resin, polyurethanes, modified cellulosics and polyamides.

1.4 Ink Characteristics

Ink can not only be defined by its colour. Except the colour there are many more characteristic that make every ink unique. Following are some of the characteristic of ink:

- **Saturation:**

It defines the saturation of colour, either it is fat or lean.

- **Feathering or bleeding:**

It can be defined as the inconvenience to write on rough papers like blotting paper. When we write on rough surfaces like blotting paper, ink feathers out or bleeds and gives writing a ugly appearance. It makes letters like ‘a’ or ‘e’ unrecognizable in some cases, especially when broader nib pens are used.

- **Lightfastness:**

It can be examined by placing the writing sample against the window in direct sunlight and measuring the saturation of ink colour after three days.

- **Water fastness**
- **Shading:**

When we write slowly by applying more pressure, more ink from the nib of the pen is applied on the paper. On the other hand if we write faster with slower pressure then less

ink will be applied on the paper. This darker and lighter ink line creates different saturation and appearance. Shading can be used to write captions of headings to create a vivid and three-dimensional look.

- **Time to dry:**

It is the time an ink takes to dry once it is applied on the paper. It majorly depends on the type of base used in the preparation of ink.

1.5 Pigments and Dyes:

Pigment

Pigments are dry, powdery substances or tiny coloured particles like certain minerals. They are mixed with water to leave various colours. Pigments are insoluble in water. Particles of pigments are very small in size and cannot be seen by naked eye, but they are bigger than the dye particles. Being insoluble in water they are found suspended in throughout the medium. Pigmented inks are found to be waterproof. The particles of pigments usually bond to the edges within the medium, this blocks the light and results in opacity of the ink. Pigment based inks last longer and resists fading of ink over time. Colour intensity of pigmented inks is more as compared to dye based inks (9).

Dye

Dyes are water soluble colorants that completely dissolve in a medium. They provide colour to the vehicle but can't be distinguish from it once they are properly mixed. They are cheaper then pigmented inks. Dye based inks take more time to dry and are not waterproof. As compared to pigmented inks, dye based inks are less opaque and also make colour appear less intense. Various different optical compounds are added to dye based inks which enhances and produce brighter colours. When exposed to sun they fades faster because they have low resistance to light and U.V. rays (9).

1.6 The Base of ink:

The base of the ink is the carrier or the vehicle in which other constituents of ink like additive, binders, pigments binds together in order to transfer it to the medium. The base of ink is of following types:

- **Oil-based ink**

Oil-based ink are those which consist of a dye dissolved in oil. The relative viscosity of oil makes ink thick, as a result it runs more slowly and as a result it last for longer time. Oil-based inks dries quickly and do not smudge. These inks are mostly water-resistant and waterproof. Oil based inks may be coloured with pigments or dyes. Unlike water-based inks these inks can also be used on glossy surfaces like receipt paper, magazine covers because of its adhesive nature. Example of oil-based ink pens includes ball-point pens and markers.

- **Water-based ink**

Water-based inks are the most common type of ink carrier. These are used for both writing pen and art pens. Pens which use water-based ink have thin nibs as compared to oil-based pens. These inks are free flowing, runs out easily and quickly and provide a very smooth writing experience. They produce nice even line that do not break. Water-based inks is not a good choice for glossy surfaces as it take more time to dry, and are easily absorbed into the paper. These inks can use both dyes and pigments to colour and have various other characteristics depending upon the type of additives added to it. These inks are available in water resistant and even waterproof varieties. Water resistant inks mostly use pigments instead of dyes. Examples of water-based ink pens include gel pens, fountain pens, rollerball pens and calligraphy pen.

- **Gel-based ink**

Gel-based ink is the combination of both water and oil-based inks. They make a water-based gel by combine the qualities of both water and oil. This combination result in a gel that is not as viscose as oil but is much thicker than water. Gel- based inks dries very fast and won't smudge, and gives a smooth writing experience. This gel is a great carrier for pigments. It can even carry metallic pigments which are not possible with water and oil based inks and thus helps in making sparkly inks.

With the advancement in technology, pigments from different sources are becoming popular like chemical based pigments, or petroleum based carriers. In 1900s these chemical based combinations of ink gained popularity because petroleum based carriers

have a property of drying fast which helped the newspapers to dry easily in less time as compared to carriers which are not based on petroleum. In 1970s due to oil crisis prices of petroleum raises dramatically. This begins the search of petroleum alternatives.

1.7 Types of Ink:

Ink is of various types. The most common type of ink is the ink used in pens. Ink also differs depending upon the type of pen used, for example ball point pen ink is of different type as compared to fountain pen ink. The various types of writing inks are as follows:

1) Ball-point Pen inks:

John Loud in 1888 patented the first ball-point pen in US. He found that these ball-point pens are better than fountain pen when it comes to write on rough surfaces. Ball-point ink pens are the most common and widely used pens in day to day life. These are basically oil based, pigments are suspended in this base. There are number of pigments or dye available, for example carbon black for black ink and for blue ink phthalocyanine blue can be used. The oils used in the preparation of these inks are of different types, most commonly used oil is 2-phenoxyethanol. When one applies pressure to the ball of the pen, ink from a tube flows in the pen and to the tip of the pen through a small ball. This oil-based ink dries faster than other inks which promotes to less smudging during writing. Ball-point ink pens are very long lasting as these inks are thick so they use less ink during writing. Due to thick nature of these inks, we need to apply more pressure during the writing process. These pens are available in a wide range of colours (10).

2) Rollerball pen inks:

In 1963 Ohto a Japan based company was the first who bring this liquid based rollerball pen in the market. Rollerball pens are very much similar to the ball-point pens, but use water-based ink or gel-based ink and as a result require less pressure on the tip during the writing process as compared to the ball-point pens. These inks flow smoothly over the paper surface and thus result in a fine and dark writing lines. These pens even come with a thin tip of 0.5mm rollerballs. These pens come in a wide range of colours because they use water-based dyes.

Disadvantage of rollerball pens is that it doesn't work well with glossy surfaces because the ink usually sinks into the writing surface instead of sitting on the top of it like ballpoint pens. Rollerball pans use more ink than other types of pens. Ink of rollerball pens dries faster if left uncapped.

3) Gel ink pens:

In 1984, Sakura a Japan based company first invented gel pens in the market. These pens are similar to rollerball pen but instead of a water base they are gel-based. This help in free flow and smooth writing experience with gel pens. These gel based pens accumulates many different types of pigments like iron oxide and copper and have high viscosity. Gel pen ink is thick and opaque in nature and is available in almost every variety of colours. The most common thickening agent used in gel pens is xanthan gum. Glitters or sparkle, metallic flack and neon colours also make these gel ink pens unique. Similar to rollerball pens, gel ink pens also consist of a rollerball at the tip of the pen which helps to distribute the ink (11).

4) Fountain Pen ink:

Fountain pen ink is hard to define. These pens are similar to drawing pen but unlike drawing pen fountain pen consist of a refillable cartridge. They are water based ink and use dye for colour. They also contain a surfactant that controls the flow of the ink from the nib of the pen to the paper. These inks are always non-corrosive in nature. Other characteristics of fountain pen inks is they can be water-base or iron gall, lubricated, quick drying, can be handmade and fluorescent.

5) Hybrid ink:

Hybrid ink as the name suggest is the combination of ball-point inks and rollerball inks. This means hybrid inks are both water and oil based inks. They have qualities of both types of pens. They have strong colours, quick in drying, and can write on all types of surfaces including glossy surface.

6) Drawing pen ink:

Drawing pen inks are water-based inks and use dye for colour. Drawing ink always require a pen which can be used to dip into the ink. When the nib of the pen gets dipped

into the ink, it gets collected at the tip of the pen. Using these drawing inks require a lot of patience and practice. They are very thin in nature and also fade with time. These inks are especially used by calligraphists and artists.

7) Felt Tip Pens:

Felt tip pens are similar to ballpoint pen in many aspects but differs in tip nub. Felt tip pen nub is thin and are more expensive as compared to the ballpoint pen nub. Felt tip nub helps the writer to add personal style to the writing. Similar to the ballpoint pen, felt tip nub also utilizes capillary action to funnel ink from the cartridge of pen to the paper.

8) Marker pen:

Marker pen itself comes in different types of ink i.e. water, oil, pigment and alcohol based. Water based inks and Pigment inks are basically used for traditional paper type. For the purpose of non-paper media like plastic, glass or metal oil-based and alcohol – based inks are used. These pens include variety of pens like highlighters, permanent markers, non-permanent markers like dry erase markers and porous point pens. They are available in wide range of point sizes, colours and types (12).

9) Iron Gallotannate Inks:

Iron gallotannate inks are also known as common ink, oak gall ink or iron gall nut ink is a purple-black or brown-black ink made from iron salts and tannic acids from vegetable sources. It was the standard ink formulation used in Europe for the fourteen-hundred-year period between the 15^{th} and 19^{th} centuries, remained in widespread use well into the 20^{th} century, and is still sold today.

The ink was traditionally prepared by adding some iron(II) sulfate ($FeSO_4$) to the solution of tannic acid, but any iron ion donate can be used. The gallotannic acid was usually extracted from oak galls or galls of other trees, hence the name.

10) Carbon Inks:

Carbon ink was essentially produced from the smoke of green pine. Lampblack was extracted from the pine and placed in the form of cakes.

Carbon ink is one of the oldest forms of writing ink. This class of ink is still widely used in the Far East and by artists worldwide. In the simplest form, carbon inks consist of amorphous carbon shaped into a solid cake with glue. It is converted into liquid for writing by grinding the cake and suspending the particles in the water-glue medium. The brownish tone of the carbon is generally corrected by the addition of colouring matter. For white colour, the colour treated with white lead, black is obtained through various types of charcoal and soot.

Carbon inks are very stable and are not decomposed by light, air, moisture, or micro-biological organisms. They are insoluble in water and can be removed from paper only by abrasion. Therefore, the ink will endure as long as the paper. This class of ink is usually unsuitable for fountain pens, but is used extensively as drawing inks and printing inks.

11) Erasable ink:

Erasable ink pens consist of thermochromic ink which can be easily removed by rubbers incorporated at the cap or end of each pen. For an erasable ink, the writing strokes were manipulated manually using the incorporated erasure. These are thermal inks which depend on temperature.

When heat is applied through friction or any other medium then this erasable ink disappeared and if kept at low temperature then they again become visible. It was found in the literature that most of the erasable inks disappeared above 57℃ to 60℃ and they again become visible at 0 ℃ to -3 ℃. It was revealed by optical microscopy that these inks have a granular structure, due to microencapsulation of the ink. Most of the granules are in 1-2µm in size and few of them are up to 8µm in size.

The basic composition of erasable inks include colorant, resin which is soluble in organic solvent, surfactant, auxiliary separating agent and fatty acid esters.

Examination of these inks by U.V. light, oblique light, IR light can reveal the erased ink lines. Video spectral comparator (VSC) can be used to decipher erased writings of thermal ink (13).

12) Disappearing ink:

Disappearing ink is water based acid-base indicator which turns colourless when exposed to carbon dioxide (CO_2) present in the environment and again becomes coloured or visible when basic environment is provided. Disappearing ink can be easily prepared in a laboratory.

The basic composition of disappearing ink consist of an acid-base indicator, ethyl alcohol, glycerol, sodium hydroxide and distilled water. The most common acid-base indicator use in the preparation of disappearing inks is Thymolphthalein ($C_{28}H_{30}O_4$) for blue ink and Phenolphthalein ($C_{20}H_{16}O_4$) for red ink. Concentration of sodium hydroxide decides the stability of disappearing ink, increasing the concentration of sodium hydroxide leads to increased stability of the ink and vice-versa.

Depending upon the concentrations of sodium hydroxide, pH indicator (thymolphthalein) in the ink solution and various conditions like humidity, temperature etc. fading period of disappearing ink can be decided. It may ranges from a few minutes to hours or days in some cases.

In fact, disappearing ink leaves a residue of Na_2CO_3 on paper, which otherwise is not visible to the naked eye, but fluoresces under a spotlight. These disappearing inks on documents can be visualized by video spectral comparator (VSC), U.V. light and various chemical methods like iodine fuming etc.

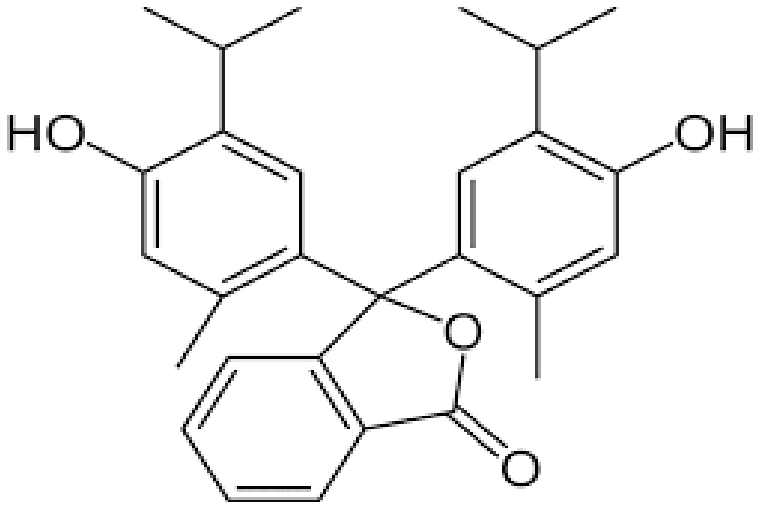


Figure 1.2: Chemical structure of Thymolphthalein

Table No. 1.1: Chemical properties of Thymolphthalein

Chemical Properties of Thymolphthalein	
Chemical Formula	$C_{28}H_{30}O_4$
IUPAC Name	3,3-bis(4-hydroxy-2-methyl-5-propan-2-ylphenyl)-2-benzofuran-1-one
Molar Mass	430.54 g•mol^{-1}
Appearance	White powder
Density	0.92 g/ML at 25°C
Melting Point	248 to 252°C (478 to 486°F; 521 to 525 K)
Water Solubility	Insoluble

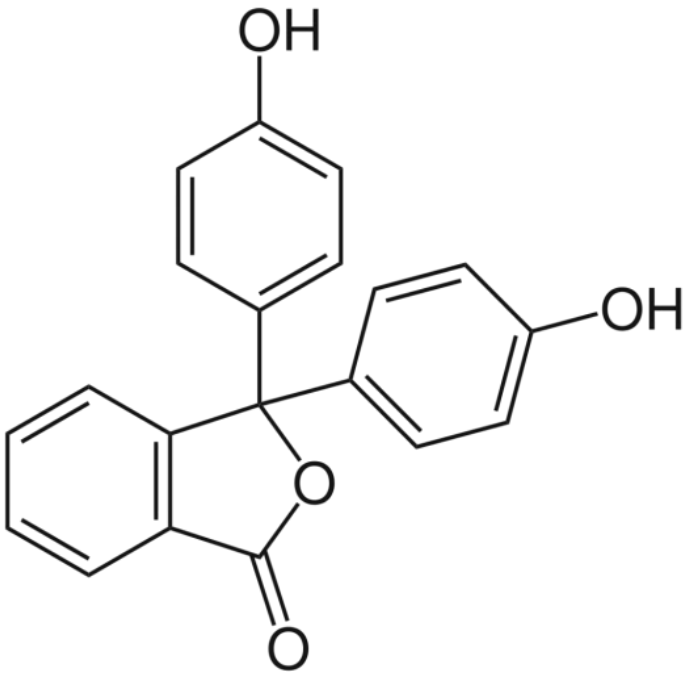


Figure 1.3: Chemical structure of Phenolphthalein

Table No. 1.2: Chemical properties of Phenolphthalein

Chemical Properties of Phenolphthalein	
Chemical Formula	$C_{20}H_{14}O_4$
IUPAC Name	3,3-Bis(4-hydroxyphenyl)-2-benzofuran-1(3H)-one
Molar Mass	318.328 g•mol^{-1}
Appearance	White powder
Density	1.277 g/ML at 32°C
Melting Point	258 to 263°C (496 to 505°F; 531 to 536 K)
Water Solubility	400mg/L

1.8 Video Spectral Comparator (VSC):

VSC is a instrument which is designed to meet various requirements of forensic science laboratories, government bodies and other immigration authorities. This instrument is equipped with different advanced features which help to examine, compare and authenticate different types of important documents like passports, wills, cheques, property documents, travel documents, banknotes, art works, artifacts, etc (14).

Figure 1.4: Video Spectral Comparator - 8000

Components of video spectral comparator are laser induced breakdown spectrometer, monitor and computer. It also comprises of camera and different light sources like U.V., IR, Laser and different filters which helps in the examination and comparison of documents.

1.8.1 Features of video spectral comparator:

VSC is a versatile instrument and considered as a case work management system for the examiners dealing with document examination. It consists of following features:

1) Hi Fi Imaging Technology: This feature helps in providing high quality images by using optical system that helps in minimizing chromatic aberration and spatial distortion in the entire magnification range.
2) High Resolution Imaging System: It helps in offering high resolution images
3) Full Range Light Source: It helps in the examination of Infrared Florescence of inks by using high intensity illumination. It also includes transmitted and incident U.V. to IR.
4) Graphic User Interface: This feature of VSC helps the users to navigate and operate the whole system easily. Different features can like filters, magnification, image processing functions, light sources, image analysis can all be operated easily by clicking on screen icons.
5) Multiple Laser Images (MLI): Side lights of VSC can be used to view Multiple Laser Images and changeable laser images. VSC's hologram imaging LED range can also be used which provides great flexibility.
6) Latent Images: This is a new feature or a filter that helps in detecting security images on various documents and also enhances these images.
7) Intelligent software: VSC is an intelligent instrument that automatically make different combinations of filter and illumination for analysing different images.
8) OVI Imaging: OVI is an optical viewer that helps in creating OVI print images from 2 angles, both incident at 45^{o}
9) Image comparison: This feature helps in the successful comparison of two documents at the same time by splitting the screen, alternate strobe and overlay.

10) Micro-spectrometer: It is a real time grating spectrometer that gives high resolution spectra of transmittance, absorption, reflectance and fluorescence.
11) Image integration: This is a feature that helps in examining fraudulent alteration in a document by analysing variation in IR fluorescence of two inks.
12) ICAO Data Reader: The OCR helps in operation like checking data in the machine readable zone of ID cards and passports.
13) Areas of Interest Processing: This feature helps in selecting a particular area of interest in an image, it improves the image enhancement results.
14) Bar code Reader Deciphers: 1D and 2D Bar codes including PDF417 format can be examined by this feature.
15) Image Measurement: This feature of VSC helps the examiner to detect various measurements in an image like angles, shape perimeters, distances, circle radii and areas.
16) Birefringent security Features: It is an anti-counterfeiting action used on various documents such as currency, cheques, credit cards, access control cards, gift cards etc.
17) Colour measurement: This helps in comparison by characterizing colour of a particular area of an image with standard colour coordinates.
18) Image enhancement with pseudo colour mapping
19) Invisible information decoders
20) Image processing and enhancement
21) Programmed examinations
22) Hyper spectral imaging

The new versions of VSC are integrated with single user document database system which helps the operator to create their own database. An operator can also access the data from the database of security document, called as keesing database. Keesing database consists of images and data related to security documents like driving license, passports, ID card from around 180 countries.

In the field of questioned documents VSC is the most advanced instrument comprising latest technology. It is considered as the most versatile system. VSC is the advanced

digital imaging system which enables the document examiner to examine counterfeit, alteration or irregularities in a document by utilizing wide range of facilities.

VSC consist of powerful tools and software that helps in the decryption of digitally encrypted data and also helps in image enhancement. It combines multi-spectral illumination and high resolution optics with the software. It makes comparison with security documents easy by giving access to optical reference database.

1.8.2 Key Specifications of VSC:

- Digital Imaging: It consist of a digital camera with high resolution and magnification range of VSC is around x1.5 to x170 on a display monitor of 30inch.
- Key Software Features: The software of VSC includes hyper pectoral imaging module, Interactive tutorial, complete control of system hardware, Seamless integration with Document and Banknote databases and comparison, processing and analysis of images.

Video Spectral Comparator is an instrument which is designed for easy and detailed examination of Security Document and other different questioned documents. Its applications are as under:

1.8.3 Applications of VSC:

1) It is used by forensic science laboratories and also by immigration authorities.
2) It is found to be effective on all types of ID card and passports.
3) It helps in detection of counterfeits and different types of alterations.
4) It is used to reveal covert security features.
5) It helps in prosecution by providing documentary evidence.
6) It helps in generating security alerts.
7) It helps in maintaining comprehensive databases related to passport and banknotes.

1.9 Paper and its examination:

Paper is one of the most important and widely used surfaces for writing. This makes it important even in case of different forgeries. Paper is easily available in markets. There is a wide variety of paper. Paper is also encountered as evidence in many different types of cases. Paper is manufactured by using different processes, so it can be differentiated on the basis of different types. Different scientific methods can be utilized to differentiate different types of

papers. Papers differ in their physical properties like smooth and rough surface, some papers are ruled but some are plain, texture on the paper is also found. Every type of paper has some unique property of its own. This uniqueness can be utilized by the forensic document examiner to examine and identify different types of documents.

Paper is found as evidence in many cases. Some of the cases in which paper examination and identification is important for the case are:-

- Sometimes after examination it was found that the manufacturing date of the document is not in accordance with the mentioned date of the document, for example if a document is mentioned available dated 23rd June 1899 but after examination of the document it was found that the paper is manufactured around 2003.
- It needs to be examined that whether the paper is different or identical from the other papers of the same document.
- Water mark of the paper also needs to be examined to see if it is genuine or forged.
- Paper is made in the form of compact sheets by using cellulose fiber. It has uniform thickness.
- In india, during ancient times plant leaves are used as paper for writing messages. Leaves of plant named "Bhojpatra" were used for writings.
- Sheets of metal named "Tampatra" were used for the purpose of writing by Rishi and Mahatmas.
- In 3500 B.C. bark of plant named "Papyrus" was used to prepare sheets which can be used for writing.
- With latest technologies in today's world manufacturing of paper has become easy and quick

1.9.1 Manufacturing of Paper:

In 1843, Kelier was the one who discovered mechanical paper which made the production of paper more easy. In 1864, first chemical treatment which utilizes calcium bisulphate was developed. A refining process was developed by Dahl in 1884 which was based on sodium sulphate. Now, let's discuss the detailed manufacturing process of paper.

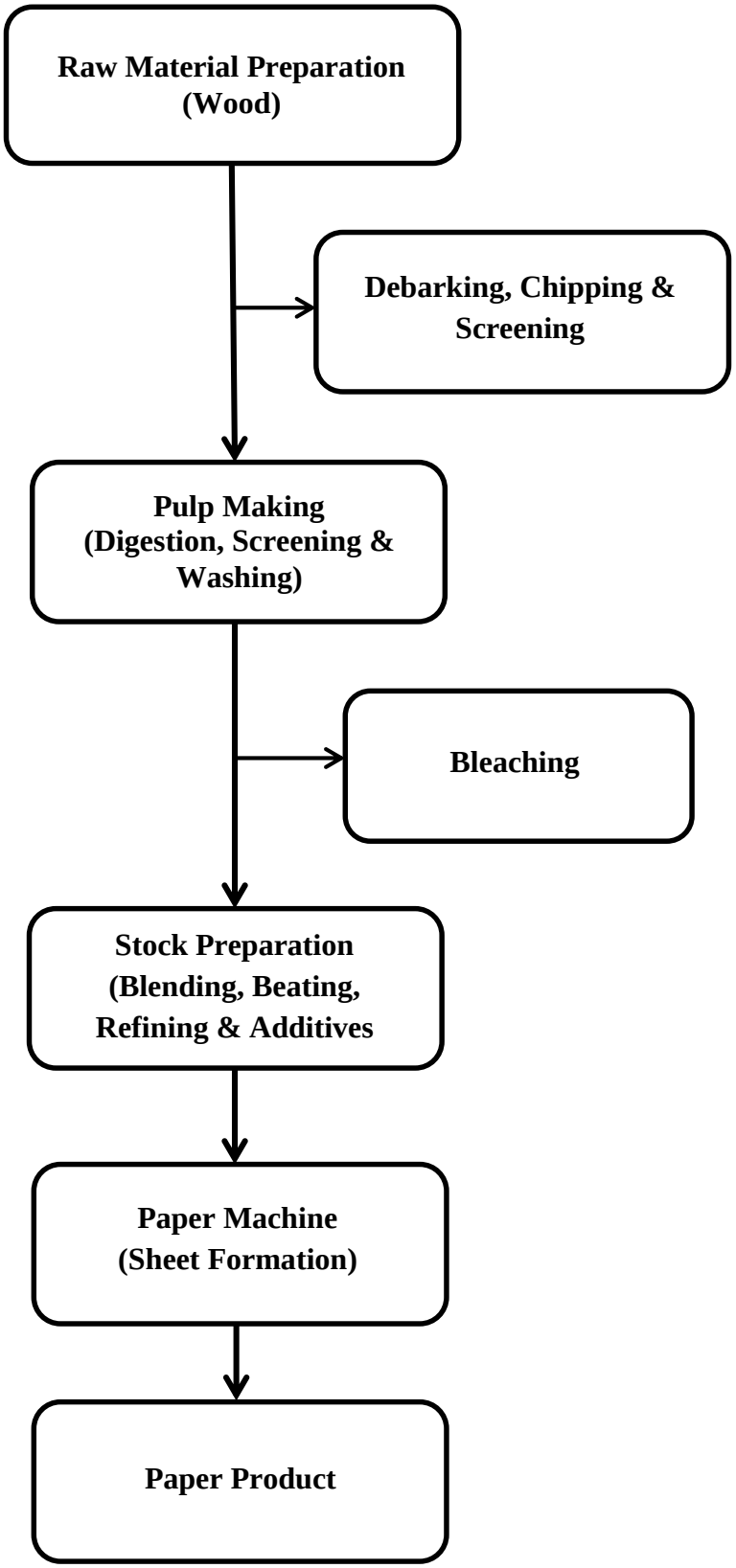


Figure 1.5: Process of Paper Manufacturing

Different substances are added to make paper of different varieties. Some of the additives are as follows:

- Rag: it includes hemp, linen, cotton and many more
- Straw Fibers: it includes oats, rice, rye, wheat etc.
- Wood: It includes trees like coniferous tree which includes fir, pine etc.
- Addition of various loading and sizing agents can help in improving the paper quality. by providing proper weight and strength to the paper.

1.9.2 Examination of paper:

There are many different procedures which can be used in order to examine and analyse different types of paper (15). Some important ways of paper examination is mentioned below:

- The colour chart can be used to compare and examine the paper colour.
- Weight: The weight of the most common paper is around 1.9 to 8.7 g/square meter. The weight of the paper is examined and confirm per square meter. Limit of difference of around 2.5% should be kept for samples that have same common origin.
- Thickness: Paper calipers and micrometer can be used to measure the paper thickness.
- Ash residue: Loading agents are mostly responsible for ash residue. Paper composed of jute, cotton, deciduous fibers and cellulose are found to have a ash residue of around 0.4 – 1.5%. Papers made up of pulp of straws and cellulose are found to have ash residue of about 2-6%, for paper made up of rice ash residue is around 14-15%. Papers which are found to have same origin can have a difference of around 4.5%.
- Microscopic examination: The papers which belong to the same batch have same distribution of fibers throughout the whole paper and ratio of these fibers is also same. To examine and study the structure of fibers in a paper microscopic study is found to be useful.
- Paper Character: Amount of fibers can be studied along with the beating degree of paper which will help in determining the character of paper.

- Fluorescence: Fluorescence of 2 papers can be compared by examining both the papers in U.V. light.
- Water mark: Strong light can be used to examine the watermark. One can also study and examine the design of watermark, its fluorescence in U.V. light and size of watermark.
- Sizing and loading agents: They are also known as the fillers. Feathering of ink in paper can be treated and stoped by using various sizing agents like aluminium hydroxide, rosin, synthetic polymers, starch and gelatin. These sizing agents can be easily detected by proper examination of paper. Cellular strength is another property provided by sizing agents to the paper. Loading agents also called as fillers helps in making the paper non-transparent and also provide smoothness to paper.
- Colouring matter: Different coloured papers are also made by using different dyes and pigments. For the purpose of examination and detection of these papers thin layer chromatography (TLC) can be performed to detect that particular pigment or a dye.
- Documents may contain fingerprint as evidence. So, it becomes the duty of the document expert to check the document carefully for the presence of any fingerprints and preserve them accordingly.

1.9.3 Other methods of examination:

1.9.3.1 Examination of Paper appearance:

Paper appearance is one of the most important factor in the examination of paper (15). It should be done carefully and following points should be considered during the examination:

- Marking of different types can be found the document which should be examined carefully. Position of these marking on the paper should be properly recorded. Different types of marks which are commonly found on paper and need attention are staple marks, indentations, punch marks, etc.

- Torn edges are also found and should be examined carefully by using the hand magnifying glass. One can also use the low power microscope to examine any cut or torn edges on the document.
- Dimensions of the paper also need to be examined carefully for any irregularities or difference.
- The texture of the paper surface should also be examined carefully.
- The location and number of folds present on the paper should also be studied.

1.9.3.2 Watermark examination:

Watermarks present on the paper are also subjected to be forged by the criminals. So, it becomes important for the examiner to examine the watermarks carefully. Examiner should have adequate knowledge about the identification of watermark in order to differentiate the genuine and the forged one. some key points which should be kept in mind while examining the watermarks. Thickness of area of paper where watermark is present can be studied in order to examine the watermark. In case of artificial watermark the thickness of the paper should be more as compared to the other part of the paper. In case of genuine watermark the paper should have equal thickness. Forgers use different techniques to apply watermark on paper like sometimes they use acid in that area in order to make paper thinner and in many cases they use grease or some oil on metal block and then press it against the paper. In this case dilute caustic solution can be used to examine the watermark. This caustic solution will dim or obliterate the watermark which is not genuine.

1.9.3.3 Fibers examination:

Fibers examination present in the pulp of the paper can also be done by the examiner. This can be done by treating the part of fragment of paper with 1% NaOH, which can be done by separation of paper fibers. After separation of fibers they need to be placed on a slide. A drop of Herzberg reagent should be added. Now the slide is ready to be examined under the microscope.

Different types of fibers used in the industry of paper are:

- Textile Fibers: They are obtained from different plants like hemp, cotton and flax etc. Characteristic features of these fibers are very narrow lumen and these fibers are very long in nature.
- Wood Fibers: They are obtained from deciduous trees like chestnut and eucalyptus, they can also be found in trees like coniferous trees such as pine. Wood fibers are smaller as compared to textile fibers. Wood fibers are found to have broad lamina and they also have wider circular orifices which are surrounded by pits.
- Starch Fibers: They are found from plants like oats, rice rye and wheat. Hair like epidermal cells and spherical or cylindrical parenchyma cells are the characteristic features of starch fibers. These fibers are found to be slenderer and also smaller.

1.9.3.4 Detection of the sizing agents:

Many different varieties of sizing agents are added to paper for various purposes. These sizing agents can be used to examine the paper which can give valuable information regarding the crime. Different sizing agents used in paper are gelatin, starch, rosin, etc.

1.10 Types of papers used in this research:

In this present research we used three different varieties of papers:

1) **Copier Paper**: It is the most common and widely used paper for different purposes. It is also called as printer paper. It is composed of cellulose fibers, pigments and fillers. Fillers like clay, titanium oxide and calcium carbonate can be used. Pigments are used in case of coloured papers. It is opaque, thin and very light in weight. It has matte coating on its surface which further helps in fast drying of the ink.

2) **Bond Paper**: Bond paper is a high quality paper which is more durable than the copier paper. It is composed of rag, cotton fibers or wood fibers as fillers. It is available in various range of thickness like 60gsm, 70gsm, 80gsm, 90gsm, 100gsm etc. We used 90gsm bond paper for our research. Bond paper is used to prepare various governments documents and bonds. It is also used by companies to prepare

their letterheads. Rag fibre pulp is mostly used to prepare bond paper which makes it more stronger than the normal printer paper.

3) **Glossy Paper**: Glossy paper is a very high quality and smooth paper mostly used to print colourful sharp photographs. It is coated with a high-shine polymer which makes it smooth. Coating of glossy paper composed of chemical additives like resins, dispersants and polyethylene to give properties like U.V. rays protection , water resistance etc. Materials like bentonite, kaolinite, talc and calcium carbonate can also be used to coat glossy paper. More smudges and smears occur on glossy paper due to its smooth surface.

CHAPTER – 2

REVIEW OF LITERATURE

Pens with invisible ink are easily available in the market. It poses a great risk to document forgery. Once the ink vanishes, it cannot be possibly detected by naked eye. This is the fundamental reason why we need to devise a practical method to identify these types of inks without risking the document/evidence in question. In recent years the cases of forgeries involving invisible inks have taken a sharp rise. Various examination methods are already available to decipher vanishing inks. The primary focus of the following literature review is to understand what the existing research findings reflect in connection to invisible ink writings and their detection. In addition to this, studies centered on different aspects of invisible ink investigation such as ink properties, composition, reaction in different conditions, etc. will be highlighted to illustrate the scope of invisible ink.

In the study, 'Identification System of Questioned Document' the authors presented 12 different standard rulings for the comparison of signatures and handwritings. These points were; uniformity, irregularity, size and proportion, loops, alignment, T-bars and I-Dots, spacing, weight of strokes, degree of slant, the needle round/wedge/flat, initial and final strokes(16).

In a research, the researchers worked on identification of ball point pens with the help of striation marks. Morphological features of about 200 Christmas cards which are written with ball point pen were examined by using stereomicroscope at 10-15X. It was found that striation marks can be seen in 37% of writings. Striation marks, also called burr striations, were irregularities or defects which occurred during the matching process of ball ink pens. These burrs scrape off ink from the ball of the pen and leave their impression on the paper in the form of striations. These striations are of different types. Striation marks within a stroke were compared in order to match the pattern. Different varieties of features like width of striation marks, width of ink deposited, blank striation number, their location etc. were suggested in order to do better and accurate identification(17).

The researchers illustrated thin layer chromatography (TLC) method used routinely in internal revenue service laboratories since 1968 for the identification of writing inks. The amount of ink required for analysis depends upon the quantity of ink deposited and

type of ink present on the document. Between 1-10 ink plugs were punched from ink stroke and dissolved in suitable extraction solvent (2 drops). The extracted ink was spotted using 5 µL micropipettes on Merck pre-coated silica gel glass plate (without indicator) and developed in ethyl acetate: ethanol: distilled water (70:35:30) and n-butanol: ethanol: distilled water (50:10:15) for at least 2 hours. The TLC chromatogram of writing inks was compared with the chromatograms present in the library. It was not always possible to identify writing inks on the basis of match with reference ink chromatogram. Two reasons were reported for the inability of identification of writing inks. Firstly, an absolute identification was impossible until sufficient standards were available for the comparison. Secondly, identification is impossible until a writing ink consists of any unique dye or combination of components. The use of multiple techniques like gas liquid chromatography (GLC) in addition to TLC was recommended to make a conclusive opinion on ink evidence (18).

According to the research, the authors described the thin layer chromatography (TLC) methodology used in the Bureau of Alcohol, Tobacco and Firearms (ATF) for studying the age of documents executed with ball pen inks. TLC was adopted as an economic and authentic tool to differentiate inks based on the dyes. Somewhere around 8-10 punches of questioned ink were removed using a blunt hypodermic needle and dissolved in pyridine. The ink extracted was spotted on Merck TLC silica gel plate and was developed in ethyl acetate: ethanol: distilled water (70:35:30) and n-butanol: ethanol: distilled water (50:10:15). The chromatogram of questioned ink was compared with the reference ink chromatograms stored in ATF ink library. The evaluation of results was based on the match and non-match of TLC profile of questioned ink with reference ink sample present in ATF library. Three possibilities were reported in case of non-match with ATF library. Firstly, the questioned ink was manufactured before 1968; secondly, the questioned ink was manufactured after 1968 and thirdly, significant physical deterioration of the questioned ink sample. Likewise, two possibilities were reported in case of match with ATF library, firstly, questioned ink could be of the same class of ink formulation stored in ATF library, secondly, similarity in ink formulation produced before and after 1968. It was concluded that dating of documents was not

possible on the basis of match or non-match of TLC chromatogram with ATF ink chromatograms (19).

Through the experiment, the authors carried out a detailed examination on fibre-tip pen inks by thin layer chromatographic (TLC) techniques. In this they collected twelve ink samples and examined all the twelve inks made with three different firms for fiber-tip pen inks. It was examined by thin layer chromatography (TLC) and concluded that it is possible to differentiate among most of these inks (20).

The study described the working procedure of High Performance Thin Layer Chromatography (HPTLC) to analyse ink samples. The stationary phase used in HPTLC was termed as concentration zone plates. The inactive layer slowed down the initial movement of the sample, whereas the active layer separated the constituent of the samples. The micrometric glass syringe was used to apply the samples on a chromatographic plate (10x10 cm) mounted on a table. The movement of the table was synchronized with the strokes of the piston operating the micrometric syringe. The ink solution projected by the syringe was pulverized by the jet of nitrogen gas. The amount of sample deposited on TLC was then checked on the monitor. The plates were developed at a distance of 3 to 5 cm and time taken for development was between 3 to 6 minutes. The results were displayed in the form of 3D graphical representation. Each graph showed multiple peaks and each peak represented the ink constituents. The position of peak represented the mass of ink whereas height of peak denoted the quantity of the ink constituent. However, only semi quantitative information could be achieved with HPTLC. The HPTLC was advised as a valuable tool to analyse ink samples qualitatively (21).

The researchers examined various colours of ball point pen ink, fibre tip and fountain pen inks with the help of high performance thin layer chromatography (HPTLC) in the study. Nearly 1 cm of ball pen ink stroke was cut and dissolved in 0.02ml of pyridine. Ink was taken directly from the ink bottle in case of fountain pen inks. The ink samples were spotted on Merck silica gel plates and developed in various solvent systems. The solvent systems ethyl acetate: ethanol: distilled water(70:35:30, blue and black) and methanol: n-propanol: 1-pentanol: distilled water (2:10:26:4, blue and red) gave best

separation for ball point pen inks. However, the solvent system iso-butanol: ethanol: acetic acid: distilled water (20:5:5:10), iso-propanol: 1-pentanol: distilled water (12:22:6), formic acid: butanol saturated with water (3:97) found suitable for the examination of of red, black and green fountain pen inks respectively. HPTLC proved to be a powerful tool to analyse ink samples (22).

The authors of the study demonstrated the methods used by questioned document examiners to analyze ink evidence since 1950. The methods include observations of ink under various wavelengths of light using dichroic filters and infrared photography. In 1960, chemical methods such as spot test, paper chromatography and electrophoresis were developed but these methods were destructive in nature. The use of thin layer chromatography (TLC) for ink analysis was first reported in 1965 and found to be an effective tool for comparison and differentiation of inks. The first TLC ink library was established by the Bureau of Alcohol, Tobacco and Firearms (ATF) in 1968. The result found through TLC could be confirmed with different analytical approaches like Gas Liquid Chromatography (GLC) and High Performance Liquid Chromatography (HPLC) (15).

In this detailed study, the author worked on erasable ink on different types of papers erased with different types of erasers. He suggested that it is very easy for individuals of average ability to alter or manipulate the documents and it is important for the forensic examiner to detect these types of alterations in the documents (23).

The authors of the research studied the aging of ink to find out the order in which they were written and suggested that it is the comparison of inks on the same paper and with the same formula. They use the solvent extraction technique to distinguish different inks. Extraction rates are obtained by utilizing two different procedures, first is R ratio and second is L, the extraction time procedure. Percent extraction was measured by utilizing the third procedure i.e. the sequential solvent extraction procedure. It can also be used to determine the extraction rates. The TLC method was found to be the best method for percent extraction of individual dye components (24).

The research investigated the time-domain and spectral coherence correlation between various kinematics variables and pen pressure (APF, axial pen force) in writing cursive

script and drawing simple patterns. Findings of the study showed that cursive script has the lowest coherence, whereas the overall coherence decreased further with complexity of the pattern. Upon observing separately, it was observed that a small number of samples of "biochemical coupling" between displacement and force occurred in cursive writing. Most of the samples displayed little coherence and the correlation was also found to be low between APF and kinematics. However, the APF patterns in cursive writing revealed moderate to high replicability. Thus, it established the concept of a "centrally" controlled pen pressure (25).

The author in the study reported a case of a local merchant who cashed a cheque of $200 but it was processed as only $2. Upon further investigation it was found that the cheque was written with the disappearing pen. He suggested the methods to detect this type of fraud in the documents (6).

According to this study, the researchers showed the effects of sliding and static friction on pen control dynamics through a computer simulation. These lead to different hypotheses on the role of friction on pen control. It was suggested that a small amount of friction is necessary to keep the pen dynamics stable while undergoing changes in pen speed. Data for the study was gathered from 11 adults where a series of words were written on different surfaces, at different speeds and in different script sizes. X,Y coordinates were recorded for axial pen pressure information. The pen pressure results recorded were analysed to check the hypotheses of earlier researchers on variation in pen pressure. Ultimately, a theoretical model of 'perceptual instrument' was proposed to describe the apparent sensitivity amongst the writers in the modulation of pen pressure (26).

In the study, the author described thin layer chromatography (TLC) technique for examination of coloured components of writing inks and printing. The process involves using the original stage of phthalocyanine pigment separation and other "slightly soluble" pigments (27).

The research reported on a feasible study on dating of ink and gave an introduction on the techniques to estimate the aging of ballpoint inks. The techniques mentioned in the study were based on micro-spectrophotometric determination of colour change rates in

inks due to the reaction with different chemicals. There are a number of procedures or methods used which include several techniques. Firstly, the rate of change of colour of ink is determined by micro-spectrophotometric methods. Secondly, masses' ratio of volatile component or dye component is determined by using both spectrophotometric method and gas chromatography in combination. Thirdly, age changes in colourless non-volatile components of ink and in resins present in ink is determined by using TLC and UV light illumination (28).

The study was conducted by taking nine different stamping inks to be analyzed by raman spectroscopy and high performance thin layer chromatography (HPTLC). Raman spectroscopy was involved to identify the spectral pattern of stamp inks and other inks and HPTLC chromatogram was taken into consideration. Blue stamp pad ink was used. However, Raman spectroscopy fails to resolve the exact sequencing (29).

The researchers studied and examined questioned documents of different kinds of criminal and civil cases for analyzing stamp ink. Two capillary electrophoresis techniques were used for this purpose namely capillary zone electrophoresis with electrospray mass spectrometric detection (CZE-ESI/MS) and micellar electrophoretic capillary chromatography with UV/Vis diode array detection (MECC-DAD). The colours of ink used in this research were blue, red, violet and green. UV-Y spectra and migration time were the most important terms for effective differentiation. However, violet and blue inks were differentiated by CZE-MS (30).

The authors of this research studied gel pen inks with new chemical characteristics. It was introduced into the US from Japan and was water-based that can be easily distinguished with other pens by its chemical composition and properties. Non-destructively, gel pen writing can be examined to identify ink absorption on paper fibres. It could also tell the overall line quality of the writing and colour difference. Ultraviolet and infrared light were also used to differentiate gel pen inks from different other writing inks (11).

The research illustrated the quality control process for thin layer chromatography (TLC) to obtain reproducible results. Pyridine was recommended to extract solvent based inks whereas ethanol: water (1:1) was used to extract water based inks. Nearly six to ten

microdots of ink line provide an ideal ink concentration. The spotting of the ink sample was carried out at 19 mm from the base of the plate. The plate with the spotting was air dried before development. Three solvent systems, namely, n-butanol: ethanol: distilled water (2:1:1), ethyl acetate: ethanol: distilled water (70:35:30) and cyclohexane: chlorobenzene: ethanol (10:2:1) were recommended to analyse ink formulations. The chambers were saturated with solvent systems 15 minutes before development to avoid edge effects resulting from the migration of dye bands at the sides of the plates rather than on the centre. The filter paper was put inside the tank to raise the saturation level. The performance of solvent systems was checked by running the standard dyes along with the ink samples. The chromatograms were placed in a film box in the freezer and a clear acrylic spray was used to store the plates. Temperature was controlled during thin layer chromatography (TLC) runs. These measures helped to acquire reproducible results (31).

In this study, the author reported the analysis of black ink writings by direct infusion electrospray-mass spectrometry (ESI-MS). Three direct infusion (ESI-MS) methods were used to analyse the menthol extracts of ink on paper samples. Each method was carried out in the presence of varied voltage, positive and negative, mobile phase additive and ESI fragment or applied voltage (+120V, +0V, and -120V). Inks were differentiated from each other with the help of ESI-MS analysis and comparisons of the observed ion data in binary form. Pair-wise comparison of observed ion data could differentiate 29 of 30 ink samples with the help of all three instrumental methods (9).

The author of the study described a reliable and strong model for studying handwritten on-line curves. Biased and weighted harmonic means are considered as a graceful mechanism or tool for combining errors from multiple models. A successfully tested signature verification algorithm is also described. The approach relies mainly on the shape of the signature for automatic verification and breaks the traditional method of relying on pen dynamics (32).

According to this study, the researcher used laser desorption ionization mass spectrometry (LDI-MS) method to investigate red ink entries of seals on paper. In the study 6 different dyes were used namely seals, bronze red, scarlet seals, fast red R,

pigment red 22, basic violet 3 and pigment red 112. The results were verified by electrospray ionization quadrupole time of flight mass spectrometry (QTQF-ESi-MS/MS). On the basis of absence or presence of their pigments in LDI-MS spectra, the 38 ink entries were classified into 6 groups. LDI-MS provides rapid and sensitive results and can easily distinguish the red ink entries of seals from paper substrates (33).

The research helped determine whether flakes of ball-point pen could reveal that the ink entries were executed at one or different time. Twenty ball-point pens were used in writing a sentence containing the same words with normal writing pressure. After writing, the pens were left open in an air-conditioned lab (17°C) with humidity adjusted between 48% - 55%. The same pens were again used to write the same text with a time interval ranging from 10 to 60 minutes. The writings were then tested for flakes and were observed as dry, flat and brittle with a high shine under oblique and episcopic light at 12X and 100X. The physical characteristics of flakes were different from gooping and blobbing. Out of twenty samples, eight showed flakes after 10 minutes of non-use. Flakes were observed either at the start of the stroke or did not appear throughout the stroke. All ball point pens were capable of forming flakes but were not consistent. It could be due to the amount of ink left on the ball of the pen, pressure applied during the formation of the stroke, or the orientation of the ball with respect to the angle of the pen and direction of stroke. The flakes could be a result of genuine delay as well. The presence of ink flakes could not determine whether the ink entries were made genuinely or with fraudulent intent. Therefore, opinions based on ink flakes must be considered cautiously (34).

The researchers of the study tested neuro-motor noise theory of Van Galen and Van Gemmert (1997, 1998) with the other existing chronometric approaches. They tested a theory that on-line adaptations to the rescaling of visual feedback are better described by the neuro-motor noise theory of Van Gemmert and Van Galen (1997, 1998) than by traditional chronometric approaches. According to this process, demand observed in deteriorated signal-to noise ratios (SNRs) in neuro-motor system is equivalent to a change in the scaling factor of slant or size (35).

In this research the chemical eradicators using acidic Clorox solution, alkaline Clorox solution and alkaline hydrogen peroxide were studied. The study revealed that alkaline Clorox erasure could easily remove the two blue aqueous inks that were able to oxidize readily. On the other hand, Reynolds ballpoint pen with black ink underwent oxidation at a moderate rate. Bic & Stick ballpoint pen with blue ink and black aqueous ink showed slow oxidation. It was found that the rate of colour change of inks depends on ink, chemical erasure and paper used (36).

The study was aimed at the analysis of ink by chromatographic and electrophoretic techniques. Inks are produced from different substances that show different chemical characteristics. Different methods were analysed such as thin-layer chromatography, chromatography and electrophoresis, high-performance liquid chromatography, gel electrophoresis, gas chromat6ography and capillary electrophoresis to explore possible ways for the separation of components of ink (37).

The study investigated the evidential value of black and blue ballpoint pens in Australia. They examined 49 blue & 42 black ball point pen inks of different models, brands and batches available in the Australian market. Three different techniques were used in the study: reflectance visible micro-spectrophotometry (MSP), filtered light examination (FLE) and thin layer chromatography (TLC). The results reflected the efficiency of individual techniques to differentiate between models, brands and batches of inks (38).

Researchers in the study described a general procedure to examine writing inks using thin layer chromatography (TLC) along with the chemistry of writing inks. Writing inks used mainly consisted of colorants, vehicle and resin binders and classified into ball point pen and non -ball point pen inks. Non ball point pen inks could be further divided into water based and solvent based inks. Ball point pen inks composed of glycol and alcohol based solvents, soluble dyes and occasionally suspended pigments. Pyridine and ethanol: water (1:1) was used to extract the ball point pen and non-ball point pen inks respectively. About 10 plugs of 1cm ink line were removed and placed into a vial containing extraction solvent. About 1.0 µL of ink sample was spotted on polyester silica gel plates using micro-pippets. The spotted plate was then put in the oven for 3 minutes at 95°C to separate extraction solvent. The plate was cooled at room

temperature and developed up-to 4 cm using ethyl acetate: absolute ethanol: water (70:35:30). The developed chromatogram was compared with the chromatograms stored in the writing ink library with respect to number, colour and Rf value of spots. The possible matches were again examined with n-butanol: absolute ethanol: water (50:10:15). Thin layer chromatography could not be used as an identification method unless a collection of inks are manufactured throughout the world. TLC was found to be a strong forensic tool for the analysis of writing inks (39).

With this research, the authors studied to develop a process known as direct ink stamp (PDMS) and low viscosity ink resist. In the process, propylene glycol monomethyl ether acetate (PGMEA) was diluted and novolac was used. For obtaining hydrophilic surface, soft stamp and metal coated glass were treated with UV ozone. In this study, different process conditions were optimized such as resist viscosity, surface energy of stamp and substrate (40).

The authors reported in their study about the different forensic techniques being used since the beginning of 20th century for the forensic examinations of ink. The International ink library, which is maintained and controlled by the United States Secret Service, has also backed these analyses (41).

In this research, the authors studied ballpoint pen inks and liquid inks (blue & black) using fourier transform infrared spectroscopy (FTIR), thin layer chromatography (TLC) and Raman spectroscopy. TLC was performed on Merck silica gel aluminum plates. Small ink lines in a few centimeters were scraped and dissolved using dimethyl formamide: chloroform (9:1). The spotted plate was then air dried and eluted using a mixture of ethyl acetate: isopropanol: distilled water: acetic acid (30:25:10:1). The chromatograms were viewed under visible and ultraviolet light. Distinction was made on the basis of different Rf and colour tones of bands. The samples remained undifferentiated by FTIR and Raman spectroscopy, and were completely discriminated by TLC (42).

In this experiment, researchers studied the thin layer chromatographic (TLC) technique to determine the changes in ballpoint pen ink dye developed with writing age. A 1 cm line was drawn with ink and then cut and placed in the Eppendorf tube. A solvent of isopropyl was prepared to elute the ballpoint ink spots. The spots developed on the TLC

plate were analysed with the help of a TLC scanner at 580 nm. A relation between the ratio of writing age and peak height was obtained. The method proved to be significant in gathering evidence to identify the age of ballpoint pen ink (43).

The study focused on analysing and developing software for recognizing handwritten scanned documents which has many applications in the field of forensic science. Different machine learning algorithms were used in scanned image examination. Scanned images are mostly stored as grey scale images of discrete pixels, which can later be converted to a pure black and white image by a binary algorithm (4).

The authors of the study advocated the need for a scientific examination of writing ink for document examiners. Various government and private agencies were using ink examination techniques to confirm the authenticity of question documents. The study takes into account all the major developments in identification and examination of ink from 1950-1990.The techniques included were the paper electrophoresis, paper chromatography, paper chromatography, micro-spectrometry, luminescence, diffuse reflectance infra-red fourier transform spectroscopy (DRIFTS), laser excitation and spectroscopy, luminescence photography, thin layer chromatography TLC), capillary electrophoresis and high-performance liquid chromatography (HPLC) (44).

In this experiment, the researcher studied ball point pen inks with the help of thin layer chromatography (TLC) and Raman spectroscopy. A total of 16 blue ballpoint pen inks of different labels were taken and used to write on paper. TLC examination was conducted using 29 elution and 17 extraction solvents. Out of all the samples, 3 elution and 3 extraction solvents showed promising results. Paper blank was also spotted along with ink samples. The chromatograms obtained were visualized in the visible and ultraviolet light. The results were then evaluated on a scale of three degrees - different, difficult to differentiate and non -differentiable. The discriminating potential of TLC to discriminate ball point pen inks was found to be 95.8% (45).

The researchers studied the dating of ink inside the pen cartridge. Ink containing methyl violet from various old and new pens were taken on paper samples and analysed through laser desorption (LD) technique. Mass spectral studies containing methyl violet have exhibited the process of dye degradation over the period of time.

The relative age of the ink could be identified using this information obtained through the LD mass spectrum (46).

The research was performed to study the characterization of ballpoint pen inks by electrospray ionization mass spectroscopy (ESI/MS) method. The acidic and basic dyes present in the inks were detected on negative and positive nodes. They analysed 44 blue, 23 black and 10 red inks for mass spectra. It was concluded that the ESI/MS technique gives a fast and simple way to compare and profile different ink specimens (47).

The experimenters in this research studied the evidential value of blue gel pen inks in Europe. They took 33 blue gel pen inks of different brands and analysed them using three different techniques: filtered light examination (FLE), raman spectroscopy (RS), and scanning electron microscopy (SEM). First, after visual examination (naked eye and stereo microscope), it was possible to classify the 33 inks into three groups described as: milky, metallic, and normal. The results showed that RS and SEM were more conclusive than FLE. The highest degree of differentiation was achieved using a combination of RS and SEM techniques (discriminating power = 0.91) (48).

According to the study, the researchers investigated the evidential value of blue gel pen inks in Europe. In this study, a total of 33 blue gel pens were collected from various brands available at the time of study in the European market. The ink samples were analysed with the use of 3 techniques: Raman Spectroscopy (RS), filtered light examination (FLE) and scanning electron microscopy (SEM). It was noted that after the visual examination, the 33 ink samples could be classified into 3 groups namely; milky, metallic and normal. It was found that different techniques respond differently according to the brand of the pen/ink. The study also concluded that SEM and RS were more effective as compared to FLE (49).

In a research black gel pen inks using mass spectrometry and gas chromatography (MS-GC) and thin layer chromatography (TLC) were examined. Twenty nine black gel pen inks were collected from the local market of the United States. The inks were primarily subjected to optical methods which studied the reflectance and fluorescent characteristics of the ink and classified 29 gel pen inks into pigments and dye-based inks. The differentiation was obtained through spot test, thin layer chromatography

(TLC), and gas chromatography/mass spectrometry (GC-MS). TLC distinguished dye based inks whereas pigment based inks were studied using GC-MS. The GC chromatogram revealed various volatile components namely, glycerin (RT-6 min), triethylene glycol (RT-12.3 min), pentaethylene glycol (RT-15.4, 18.8, 21.0 min) and triethanolamine (RT-11.7 min). The volatile components identified in black gel pen inks were different from the components identified in black roller ball pen inks. It was suggested to analyse different colours of gel pen inks using GC-MS in future research (50).

The authors reported their work on dating of ink and suggested that 2-Phenoxyethanol (PE) which is a common volatile organic compound present in ballpoint inks undergoes evaporation as ink ages. To identify the occurrence of PE in ink formulations, a total of 633 ball point inks were tested using a gas chromatograph/mass spectrometer. It was found that PE was identified in 85% of the cases, while 83% in blue and black inks (51).

The researchers reported their work on the identification of dyes extracted from textile fibres by LC-MS. A set of 22 dye materials were prepared and identified with liquid chromatography mass spectroscopy which provided information about the chemical structures. The elution of dyes was studied using a UV visible absorbance detector along with MS detector (52).

The study described a general procedure to identify an ink formula or type using thin layer chromatography (TLC). Identification helps determine if two ink formulations were of the same or different origin. Identification of a questioned ink was possible with an adequate collection of reference ink samples in the ink library. However, even with an adequate collection of reference libraries, it was not always possible to find a single match for a questioned ink sample in the reference ink library. This might be because of using similar non-coloured components (dyes or pigments) in various ink formulations which leads to similar results. Identification of questioned ink was impossible until it contained a specific ink component. Therefore, it was not always possible to identify every questioned ink. Techniques such as gas chromatography (GC), fourier transform infrared spectroscopy (FTIR) and high performance liquid chromatography (HPLC) etc. were suggested to be used to get additional information about an ink formulation (53).

The researchers carried out the work in which photo patternable silicon was used to develop microcontact printing stamps. The advantage of using photo patternable silicon was due to the fact that it is convenient, enables fast stamp fabrication and allows rapid patterning of substrates. Photolithographic process was used to get the optimal stamp surface (54).

In this experiment, the authors studied characteristics of ink on sensitive documents for absolute/ relative age determination. Tagging of ballpoint pen is an important process as it can lead to a significant breakthrough in detection of forgery in documents. The study of tagging metal ions in association with NAA and ICP-MS as analytical tools allows different combination options based on various rare-earth chelates as suitable material for tagging of ballpoint pen inks (55).

The study examined the capillary electrophoresis with UV-Visible photo iodide tool for ink examination in forensic sciences. To analyse the dye components in inks, 2 buffer systems were created. The results obtained were then compared with the TLC method to evaluate the performance and sensitivity of capillary electrophoresis (56).

In this experiment, gel pen inks were studied with the help of different physical methods and thin layer chromatography (TLC). Nearly 98 gel pen inks of 13 different colors were gathered from India, Europe and the United States. Each pen was used to write a few ink lines on plain white bond paper. The sample preparation was performed by dissolving ink strokes in methanol and acetone. The extracted inks were then spotted on precoated Merck silica gel plates and development was performed in 13 different solvent systems. Out of 13 samples, 2 solvent systems, butanol: ethanol: water: acetic acid (60:20:20:0.5) and butanol: ethanol: water (50:25:25) were found suitable for the development of chromatograms. The chromatograms were studied for number, colour and Rf value under visible and ultraviolet light (254 nm and 356 nm). It was observed that TLC was able to differentiate more than 35% of gel pen ink samples. Different other instrumental techniques like fourier transform infrared spectroscopy (FTIR), scanning electron microscopy with energy dispersive X-ray spectroscopy (SEM/EDX) and raman spectroscopy were suggested to be used for additional information (57).

The researchers of this experiment studied Rheology, which is an important tool in ink development. The main purpose of the vehicle park of the ink is to support the pigments and also to properly adhere them to the surface of the paper or the substrate. Mostly volatile substances that evaporate easily are used as solvent in the preparation of ink. Water based inks doesn't dry quickly instead they take some time to dry. The binder is used to bind all the components of the ink together (58).

The study reported the use of the technique as a general tool for gel pen ink analysis. A total of 55 blue gel pen inks were collected from different brands available in the world market. A solubility test was performed on methanol to separate them into 2 broad classes: 36 pigment-based and 19 dye-based gel pen inks. It was then visualised by Raman spectroscopy (59).

The researcher in this experiment explained the importance of ink to validate a document. Ink as writing material reveals a great deal of information about the document. It could ascertain if two inks on one document were the same. Its analysis involves studying the behaviour of questioned inks using destructive and non-destructive methods. The non-destructive methods examine the color, absorption spectra, luminescence under ultraviolet and infrared radiation and morphological features of inks. Sometimes, these methods fail to differentiate ink samples. In such situations destructive tests could be used in addition to non-destructive methods. Destructive methods such as thin layer chromatography (TLC), high performance liquid chromatography (HPLC), and fourier transform infrared spectroscopy (FTIR) etc. provide more information but require removal of some portion of ink from the document (1).

According to the study, the researchers analysed different components of the ink to identify their ageing process. It involved analysing the degradation process of two usual dues such as methyl violet and ethyl violet. The analysis was performed with the help of matrix-assisted laser desorption/ionization (MALDI), laser desorption/ionization (LDI) and mass spectrometry (MS). It was also aimed at finding the utility of these techniques in the examination and identification of forensic documents (60).

The study reported the work on writing ink analysis with mass spectrometry technique. This technique was provided with a new ion source known as Direct Analysis in Real

Time. It is a non-destructive method which helps in analysing writing inks on paper without leaving any visible mark. A total of 43 samples of different pen types were tested in the study (61).

The authors reported their work on matching of writing inks with the United States International Ink Library. The Internal Revenue Service and the United States Secret Service jointly maintain the National Forensic Laboratory. A total of 100 ballpoint pens and non-ballpoint pens were selected randomly and their ink composition was compared with the reference or standard. Whatman filter paper was used to produce writings from each collected pen. 85 out of 100 samples were found to be appropriate for comparison with thin layer chromatography and optical examination. 3 of the ink samples did not match any of the specimens on record (62).

The researchers in this experiment studied solid phase micro-extraction (SPME) technique along with gas chromatography-mass spectrometry (GC-MS). It was performed to quantify the solvents in inks. The traditional methods would lead to some degree of destruction of samples while analysing the ink on documents. Generally, the method used for removing ink from paper either involved use of paper punch or scalpel. A sampling cell was constructed to avoid destruction of documents. The sampling cell allowed the solvents to be absorbed on the SPME fiber directly. Analytical (ink volatiles) are then desorbed from the SPME fibre on a gas chromatograph equipped with a mass selective detector (GC-MSD) (63).

The authors reported their work on the analysis of dye with the help of visible spectroscopy, electrospray ionization mass spectrometry, ultraviolet, high-performance liquid chromatography. A multi-stage chromatographic technique was developed with the use of acidified acetonitrile and acidified water that identified and separated a mixture of 13 disperse and 15 basic dye standards (64).

The study focused on the analysis of blue ballpoint pen ink samples that were collected from Germany using high-performance thin layer chromatography (HPTLC). Nearly 31 blue ball point pens were gathered and used to write on multifunction bright white, wood-free and chlorine free paper. About 1cm of ink stroke was dissolved in 15uL of methanol in a vial and was kept in the absence of light at room temperature for 24 hours.

Paper dissolved in methanol was taken as control. About 2.5 µL and 5 µL of ink samples were applied onto a 10 cm x 20cm HPTLC silica gel plate with the help of a Camag Lenomat IV applicator. Methyl violet was used as standard dye and was spotted against the samples. The spotted plates used were developed using n-butanol, 2- propanol, bi-distilled water, acetic acid (10:5:5:0.5) and n-butanol, ethanol, double distilled water and acetic acid (15:3:3.9:0.45) separately. The time for development of both solvents was 15 minutes and 30 minutes respectively. 31 blue ball point pen inks were divided into 12 groups depending upon the differences in number, colour and hRf values of spots. The relative intensity of bands at 590 nm further divided the ink samples into 18 groups. The discrimination power of HPTLC to differentiate blue ball point pen inks was observed to be 92% (65).

The experimenters carried out their research on Laser desorption mass spectrometry (LDMS). It is a method used in the examination of questioned documents. It is used to detect neutral or single charge ink dyes. Different inks contain dyes which have multiple charges and cannot be analysed through the LDMS. In their report they detected the >20 polyionic dyes that can be used in the manufacture of inks (66).

The study involved analysis of various marine molluscs such as sea hare, cuttlefish, octopus and squid known to secrete and release a special type of ink when attacked by predators. The sea hare Aplysia californica secretes and releases ink from ink gland and opaline gland protect the individuals from injury and death from predatory attacks through a combination of mechanisms such as sensory disruption, chemical deterrence and phagomimicry (67).

The researcher in this experiment studied a non-destructive technique for differentiation of black ballpoint pen inks with infrared luminescence which targets variations in the emission of infrared energy of many common document material ingredients when excited by blue-green visible light. The resulting invisible emission was detected by sensitive photographic and electronic methods (68).

The experimenters studied ballpoint pen inks using thin layer chromatography (TLC) technique. Nearly 31 ballpoint pens (21 black & 12 blue) were randomly collected from the Messina region in Italy. The pens were used to draw lines on an unlined sheet of the

same batch of A4 office paper (80g/m2). About 1cm of ink line was dissolved in 40 µL of absolute ethanol in a glass vial. The blank paper which was dissolved in ethanol was taken as the control sample. About 5 µL of ink sample was spotted on high-performance TLC silica gel plates and developed using a mixture of n-butanol: n-propanol: water : acetic acid (10:5:5:0.5). Maximum differentiation was observed in blue ballpoint pen inks in comparison to black ballpoint pen inks. TLC gave high potential to differentiate ballpoint pen inks (69).

In this study, the researchers analysed the chemical composition of ink and compared it with known samples. The ink samples contained information related to the ink components and the date it was introduced in the market (70).

The study involved preparing disappearing ink with the help of different concentrations of thymolphthalein and phenolphthalein and their mixture. It was then applied to 3 different writing surfaces such as polyester, cotton and polyamide. Results of alkali, phenolphthalein and thymolphthalein concentrations on the fading time were analysed (71).

The study was focused on studying a quick and effective technique for differentiation of ink components on questioned documents. The data was collected through an image analysis software for studying thin layer chromatograms (TLC-IA). TLC was used to extract and separate ink spots with the help of methanol from the document. New software was developed to profile the intensity of colour red, green and blue (RGB). RGB ballpoint ink profiling revealed that the patterns were different for different manufacturers (72).

The study was conducted to devise a methodology to analyse ink evidence with the help of high performance thin layer chromatography (HPTLC). About 40 ball point pens were collected from the market and were used to draw lines on a sheet of ISO (12757) certified test paper. About 20 ink strokes of 10 mm each were dissolved in 10µL of ethanol: water (1:1). Camag Linomat IV was used to deposit the ink sample (10µL) on silica gel HPTLC plates. The reference dyes and paper dissolved in extraction solvent were also analysed. Camag TLC scanner III was used to measure the absorption spectrum of each ink sample at 31 different wavelengths. Ink samples were differentiated into 13 groups on the basis of their dye composition. The chromatograms were digitally stored and were used for the comparison of inks. The technique was

assessed by analysing dye ladders in different batches of mobile phases. Highest reproducibility was observed when the analysis was performed by different examiners at different points of times and locations (73).

The authors of the study analysed if standardized high performance thin layer chromatography (HPTLC) methodology could be considered to analyze ink evidence in forensic context from both a practical and theoretical point of view. It was possible to compare and identify the source of ink samples through a digital ink library. Different algorithms were used for various tasks. The information obtained through the digital library was accepted by the court of law. The methodology adopted to standardize HPTLC was suggested to be applied to various analytical techniques and other types of evidence (74).

The researchers performed sample analysis by ToF-SIMS analysis of ballpoint pen inks marking for discrimination. This technique requires less time for sample preparation and analysis. It has advantages over other techniques and methods in the forensic field due to its ability to analyse even trace amounts (75).

The authors of the study analysed the components of black pen inks. About 93 black pens were taken and classified into 2 groups: pigment-based and dye-based. The chromatographic conditions for separation of gel pen inks were optimized and were separated by using 40 mmol/L tetrabutyl ammonium bromides as ion-pairing reagents (76).

The experiment helped develop a technique to analyse dyes and vehicles of writing inks. All the samples were prepared on paper with 18 black ink pens (6 ballpoints, 6 gel, and 6 rollerball pens). Inks were extracted with the help of methanol. The identification of the ink components was performed by comparing ions present in the ink extract ESI-MS spectra with the ions present in a series of standards. The limits of detection for the standards were generally in the 2.5-10 ppm range (77).

The study was performed to identify and classify different brands and labels of gel pen ink available worldwide. Various analytical methods were performed to differentiate different components of gel pen inks. Analytical methods such as Raman Spectroscopy gave better results to discriminate between the different pigments of the gel pen ink. It

was suggested that different spectra of the same ink could be developed with different wavelengths (78).

The authors of the study proposed a new method called interval-valued symbolic features to represent online signatures. The concepts of feature-dependent and writer-dependent threshold were used to reduce equal error rate. A series of experiments were performed to measure performance of the method proposed in the study. The results of the extensive experiments revealed that the proposed representation scheme was simple and reduced the EER considerably. In this research, global features of online signatures were used to form an interval-valued feature vector (79).

The researchers examined the ballpoint pen inks using the technique of time of flight secondary ion mass spectrometry (TOF-SIMS). During the analysis, the substrate having the ink was taken off the background matrix without any interference. The spectra could be used to differentiate between different inks (80).

In this experiment, the researchers carried out a comparative analysis of ballpoint pen ink with Raman spectroscopy and surface-enhanced Raman scattering (SERS). Spectra of about 10 dyes were formed under different analytical conditions using the fourier transform system (1064 nm laser) and dispersive system (633 nm, 785 nm lasers) (81).

The authors studied different volatile organic components of black gel pen inks with the help of head space-solid phase micro extraction gas chromatography-mass spectrometry (HS-SPME GC/MS). A total of 16 black gel pens were collected from the local market of Japan, Korea and Germany. The ink samples were drawn directly from the cartridge of the pen and dissolved in methanol in a vial. The solution which was prepared was analysed using HS-SPME-GC-MS. About 20 different components were identified from 16 gel pen inks. Few ink components were specific, whereas some were commonly present in all ink samples. Two statistical tools: cluster analysis and principal component analysis differentiated the ink into 4 groups. It was possible to particularize if the inks were manufactured in Japan, Korea or Germany. The use of HS-SPME GC/MS was proposed to analyse ink evidence on a regular basis (82).

The researchers of this study reported that the ASTM standards on writing ink identification and comparison were the most recent guidelines to be published in forensic analysis of ink. The paper reviewed two standards in the context of evolutions and proposed improvements related to standardization of analyses, interpretation of ink examination and comparison of ink samples (74).

The researchers stressed about the importance of ink analysis which has been in existence since the 20th century. The United States Secret Service, which maintained the International Ink Library in the 1960s, also supported these studies. It is to be noted that before 2009, these ink analyses were performed manually. The successful implementation of this method paved the way for development of new mathematical algorithms and software packages to enhance the ink library. The forensic document experts can effectively use the algorithms suggested for comparison and examination of ink samples (83).

In this study, the researchers studied and compared the LDI-MS mass spectra of blue gel pen inks with a statistical methodology. The resultant mass spectra were then analysed with the Euclidean distance and Pearson correlation coefficient. Inter-variability results of one ink were compared with intra-variability of other inks. This comparison resulted in identifying the differentiation threshold (84).

The study suggested a new signature recognition system based on Random Transform (RT), Support Vector Machine (SVM) and Fractual Dimension (FD). Firstly, the Random Transform (RT) was performed to record the projections of original signatures. Then, Fractual dimension (FD) of 4 vectors obtained in the first step were computed to develop vectors for each signature. The vectors were then fed into the Support Vector Machine (SVM) for recognition of signatures (85).

The experimenter studied the significance of ink in establishing the authenticity of documents. Ink when used as evidence determined if two inks present on documents were same or different. Moreover, it could tell about the origin of ink, source, manufacturing and age of the ink when placed on a document. Inks could be divided into 2 broad categories i.e,writing inks and printing inks. The writing inks were further divided into 4 categories: high viscous ball point pen inks, less viscous fluid inks, the

gel inks and erasable pen inks. The most usual vehicle used in ball point pen inks was 2 phenoxyethanol and benzyl alcohol. Other ingredients include resins, humectants or corrosion inhibitors. An analyst must confirm the results with the inks present in an ink library. There are chances that the results might not always be a correct match of every questioned ink in an ink library. Two primary reasons were given: firstly ink manufacturers change few chemical constituents of inks on a regular basis which led to the deviation of results, secondly an ink undergoes several chemical changes or degradation when exposed to environmental conditions such as heat and light. The parameters were proposed to be considered before making a conclusive opinion on the identification of an ink (7).

The researchers of this experiment examined inks of ballpoint pen by using high-performance thin-layer chromatography (HPTLC) combined with principal component analysis (PCA). A total of 10 blue ballpoint pens were gathered from the market of Egypt. HPTLC analysis was then performed for pure ink as well as ink extracted from the paper. The ink samples were applied on HPTLC silica gel plates and were developed using butanol: ethanol: water (5:0.5:1.5). These 10 ballpoint pens were further divided into 3 groups based on the difference in colour and Rf value of spots. The chromatograms were measured at six different wavelengths (215,305,347,547,585 and 665nm) and the percentage of maximum height was taken for the evaluation of results. PCA was applied to the chromatograms and the first 3 or 4 principal components (PC) were used to characterize the inks. It was found that PCA analysis can be used to classify and individualize the ink samples (86).

The study focused extensively on the visualization method of disappearing ink writing. Disappearing ink pens are today used in committing various frauds mostly related to the bank instruments. These inks are visible only for a certain period depending upon the type of paper and various other factors. After some time the writing on the paper becomes invisible after reacting with the atmospheric CO_2. Due to the chemical composition, the ink is not normally visible under the UV or IR light, making it a very useful tool for forgers. Disappearing inks known as pH indicators are water based acid-base indicators, that changes itself from coloured to colourless solution when comes in contact with air. Thymolphthalein indicator is used to make this ink with the mixing up

of a basic solution but when it comes in contact with the air, it becomes more acidic and results in the colour change. Video Spectral Comparator (VSC) is the main instrument used to visualize disappearing ink writings (87).

In this experiment, it was studied the rate of evaporation of writing ink when it was placed on a substrate, a drying process begins. This process of drying depends on the composition of both the substrate as well as the composition of the ink. The examination of the ink on different conditions was also examined. In the case of polymers, the Raoult's law assumption was replaced with one developed by the Flory-Huggins theory of solutions.

The authors examined seven types of typewriter ribbon inks with the help of high performance thin layer chromatography (HPTLC). The resultant Rf values were then calculated. In this study six inks were the same, but the seventh one was different (88).

In this research the authors studied inks of marker pen which poses a very serious issue for conservators as they vanish after some time or years and also possess change in shade and colour. Marker pen inks are found soluble in most of the solvents which are used commonly. In this study, TLC (Thin Layer Chromatography) were used as a separation technique to separate complex mixtures into their individual components. Raman spectra were are used to examine different colours like orange, red and yellow of standard samples pf 2 professional and 2 consumer brands have been recorded and then identified and compared to the old marker spectra with new markers (89).

The researchers of this experiment described handwritten signature verification. The method used a neural network approach for verifying handwritten signatures. In the experiment ,300 signatures (150 genuine and 150 forged) were collected. It was found that 248 signatures were correctly identified. The correct classification rate of the system was observed to be 82.66% (91).

The experimenters in this study examined the ink lines that were extracted from the writing on white photo-copier paper. IR, HPTLC and UV-Vis spectroscopy were used to examine around ten blue ink ball-point pens. The writing inks were separated into three different groups on the basis of R(f) values of colour tones of different brands

separated by TLC. The results obtained shows that the UV-Vis spectroscopy was proved to be the most effective tool to separate the blue ink of ballpoint pen than IR and HPTLC (92).

The author studied different types of inks such as invisible ink, erasable ink and disappearing ink. Disappearing ink is a type of ink which fades with the passing of time; erasable ink is an ink which could be physically erased with the erasers with each pen. Disappearing ink can be used to forge the documents because of its nature of vanishing with the passage of time. The study involved the application of different types of ink on different varieties of papers. It was observed that the vanishing time of the disappearing ink was 2 hours on cheque, 36 hours on standard white foolscap paper and 40 hours on plain white A4 type of paper. Some areas on the paper were manipulated with the erasers incorporated within the erasable ink pen. The faded writing was visualized on treatment with weak alkaline solution such as NaOH. Erasable writing was then interpreted with the instrument Video Spectral Comparator. It was concluded in this study that the weak alkaline solution treatment was the way to decipher the faded writing and the infra-red luminescence was also effective (93).

According to this research the authors worked on the concept of secret writing. It was suggested that invisible writing is the art of concealed writing. Secret writing is used to deliver a message which is unreadable to the third-party. but it does not hide the existence of the secret communication. The study focused on the technical introduction of these secret writing for those who are unfamiliar with this field. About 27 samples containing hidden messages were written with some biological fluids, fruit juices, chemical fluid, vegetable fluids, etc. The samples were then visualized by physical methods such as UV lamps, heat treatment and chemical methods for a specific interval of time i.e. from 1st day to the 30th day with interval of 5 days (94).

The experimenters worked on the technique Hyperspectral Imaging (HSI). It is a new and handy technique for the examination and analysis of various types of inks used for writing, it also includes inks of gel pen. This technique combines digital imaging with percentage reflectance spectroscopy. In this study, the analysis of a different types of blue, black and red ink gel pen on white paper was carried out by using Hyperspectral

Imaging (HIS). They achieved 0.90, 0.40 and 1.00 discriminating powers by using HIS for blue, black and red ink gel pens respectively. The overall discriminating power of 0.76 for this Hyperspectral Imaging technique combined with minimal sampling requirements and non-destructive nature which demonstrate the significance of this technique (95).

In the study, "Forensic Handwriting Analysis : A Research by Means of Digital Biometrical Signature", it was found that the majority of people have had more difficulty in slowing their movement rather than accelerating. In all slowed signatures, there are more pauses, more fragmentation of shape and more overhead movements, furthermore people put into words their difficulty. Index of deceleration goes from 3, 60% to 84,37%, index of acceleration goes from 6,25 % to 277,97% . This research was carried out to identify if there is a constant relationship between speed and pressure, if pressure always lightened in acceleration and if it always made heavy in deceleration. This paper identified correlation between pressure and speed (96).

The experimenters of the study worked on the determination of the discriminating power of HPTLC (high performance thin layer chromatography) technique for the analysis of a set of blue ink ballpoint pen. Samples of ink accumulated on paper were extracted with the help of methanol and were separated with the help of a solvent mixture of methanol, distilled water and ethyl acetate (35:30:70, v/v/v). Crystal violet was observed as the major dye present in blue ball point inks. An additional unidentified dark blue colour band was also observed in few ink samples. The blue ballpoint pen inks were further classified into 4 groups based on differences in color tones. Group 1 samples lacked crystal violet in their ink composition. Group 2 sample consisted of crystal violet as a major dye component. Group 3 samples consisted of a light blue color band below the crystal violet band. Whereas, Group 4 sample had a light blue color band above crystal violet color band. The result obtained differentiated a few models of the same brand. The power of HPTLC to discriminate blue ballpoint pen inks was found to be 89.40%. The homogeneity of inks within the ink reservoir and precision of HPTLC technique was also determined. HPTLC proved to be an effective technique to discriminate between blue ball point pen ink samples. The authors suggested studying the relative intensity of bands to further increase the separation potential of HPTLC.

The use of multivariate statistical techniques was suggested for the interpretation of results (97).

The researcher studied many different civil and criminal cases in China. He found that most of the questioned documents were written by inks of gel pen. During the examination of questioned documents it is important to find out if all the entries are made by single pen or it is done by two or more pens of same colour ink. In this research, dissolution-diffusion rates of all the ink entries were compared in order to identify the relative age of ink entries. This method is called as dissolution-diffusion method. A solution of an-hydrous ethanol and dimethyl formamide is used as a solvent to dissolve the dye of ink of gel pens strokes. It was found that thickness of the strokes of ink, type of paper and different brand of gel pen, all these factors have significant effect on determining the age of ink (99).

The researchers of this study examined if dynamic features like velocity, size, duration, pen pressure and jerk measured by computer can differ between genuine signatures and forged signatures. Velocity, pen pressure and stroke duration were found to differentiate between genuine signatures and forged signatures. This doesn't get affected by style of model signature or style of forger's signature. The results showed that the dynamic feature of handwriting reflect that the handwriting movements characteristics for simulation is affected by the style of model signature and the style of forger's own signatures. It shows that the writing dynamics of simulated signatures has a very significant effect of the simulator's normal style of writing. Therefore, it is very important for the examiner to pay attention to the characteristics of the writing style of the writer while establishing the authenticity of the signatures (5).

The study discussed the importance of examination of gel pen inks and their differentiation. The study involved examination of twenty seven gel ink pen through visible spectrophotometry and thin layer chromatography (TLC). With the help of visible spectrophotometry inks were divided into nine groups. TLC was used to differentiate inks by using 3 solvent systems. It was found that the components of ink can be separated by the discriminating power of the solvent systems and the discriminating power of the solvent systems was found to be very significant

statistically. The result showed that the thin layer chromatography was a better technique for separating gel pen inks and visible spectrophotometry can be taken as a complementary technique (100).

In this study, the researchers analysed ballpoint ink samples with the help of thin layer chromatography (TLC). About 7 ballpoint pens (4 blue & 3 black) were gathered from Romania. The ink was collected directly from refill and was dissolved in methanol. The extracted ink samples were then spotted on Merck TLC plates using fine capillary tubes. The spotted plates were developed using ethyl acetate: ethanol: distilled water (70:35:30) and n-butanol: absolute ethanol: distilled water: acetic acid (18:2:2:1). The chromatograms were analysed under visible and ultraviolet light. The differentiation was carried out on the basis of colour tones and Rf value of the spots. The majority of the ink samples had similar colour tone but different Rf values. The samples having similar colour tone were segregated using CIELAB colour scale. The results obtained using CIELAB colour scale were highly reliable. The author of the study reported CIELAB as an excellent approach to differentiate inks of similar colour tone (101).

The researchers in this experiment identified 3 blue fountain pen ink samples of Indian origin with the help infrared spectroscopy (IR), thin layer chromatography (TLC), nuclear magnetic resonance (NMR) and ultraviolet visible spectroscopy (UV-VIS). Around 1.0-1.5 µg of pure ink was taken from the refill and was spotted on a TLC plate. The spotted plate was then subjected to development in the butanol: ethanol: water (50:10:15). The discrimination of ink samples was carried out on the basis of differences in colour tones and Rf values. TLC differentiated nearly all fountain pen ink samples. Further analysis was performed using UV-VIS, IR and NMR. In UV analysis, the discrimination was carried out on the basis of the maximum absorbance by each sample in the range of 200-280 nm. Maximum absorbance was observed at 297 nm, 296 nm and 211.03 nm. In IR, discrimination was carried out on the basis of presence or absence of a particular absorbance and intensity of in the range 450cm- to 4500 cm. In NMR, ink extract was thoroughly mixed with another solvent. Each brand showed peak at 7.0-7.5 ppm. The spectra of the majority of ink samples were found to be similar. No discrimination was made on the basis of absorbance of peak (103).

The study discussed the problems which are commonly faced in the field of forensic science. As the writing written with the erasable ink pen can be erased with the certain rubbers and re-write on the previous writing. The examination of these inks with the help of different instruments like Video Spectral Comparator, ESDA, Docucenter Nervis, Projectina Docucenter, magnifiers, etc. they suggested that the erasable ink pens are differ in stability on paper documents and can easily remove by certain erasers or heating. So the valueable documents can be grafted with some polymeric compounds like polyvinyl alcohol (pva) and polyvinyl pyrrolidone (pvp) in order to stabilize the strokes of writing of erasable ink (14).

Through the study, the researchers discussed the techniques which were commonly used in the analysis of ink between 2000-2014 through a review article. TLC is considered as one of the most significant and widely used techniques for the ink analysis. Several other analytical techniques were employed to confirm the TLC results. High performance thin layer chromatography (HPTLC) was proposed to be considered as an alternative technique to TLC. The HPTLC along with scanners and multivariate statistics provided positive results than conventional TLC. The gas chromatography (GC) was used for the differentiation of different types of ink. GCMS helped with qualitative and quantitative information about an ink formulation. The spectroscopic techniques used were not destructive and provided complete information of an ink formulation. The discrimination obtained from spectrometric techniques was non-destructive in nature. Nonetheless, some spectrometric techniques were damaging in nature and demanded high maintenance. This restricts their use in daily caseworks. Both chromatographic and spectrometric techniques were employed for the characterization and dating of inks. Characterization provides better results than dating studies. The use of different other analytical techniques for the study of different colours of ball point pen ink and non -ball point pen was proposed to be studied in future studies (2).

The author in this research formed artificial signatures by minimizing the mean misalignment between itself and the signatures from the enrolment set. These artificial signatures are called as hidden signature. They then replace the template signature with the artificial or hidden signature. The use of artificial or hidden signature opened up new paths for signature examination and analysis. Statistical properties of the hidden

signature were applied in order to normalize the error signal of the verified signature and to use the misalignment on the normalized errors as a verification basis. It showed an error rate that allowed creating a system on-line which can be operated in real world. Dynamic time warping (DTW) was used to form a misalignment score between the set of template signature and verified signatures (104).

The experimenters studied red ink sealing samples that are frequently submitted for examination in forensic science laboratories. A non-destructive technique should be employed so as to also preserve the fraudulent or forged cheques, documents etc. Time-of-flite secondary ion mass spectrometry was used for analysis of red sealing inks on paper. Red colour sealing inks manufactured in Japan, China and Korea were used for the purpose of analysis. It was found that TOF-SIMS is the most useful non-destructive technique (105).

The study involved analysis of ball point inks and erasable pen inks with the help of Infrared (IR), thin layer chromatography (TLC), Ultra Violet-visible (UV-Vis) and Raman spectroscopy. About 5 blue ballpoint and erasable pens were gathered from the market of Egypt. The ink was collected directly from the barrel of the ballpoint pen and was dissolved in isopropanol. The extract obtained was then spotted on laboratory prepared TLC glass plates. The spotted plate was eluted using a mixture of chloroform and methanol (90:10). The obtained results were examined based on difference in colour and Rf value of the spots under visible light and ultraviolet light. TLC discriminated major ink samples on the basis of difference in the ink profile (106).

The authors in the study discussed the importance of forensic analysis of ink in investigations related to forgery in passports, cheques, graduation certificates, marriage certificates, etc. As majority of the documents are written with pen, therefore he studied the characteristics of different brands of ballpoint ink pen and erasable ink pen. He analyzed different components of erasable ink pen and normal ink pen with infrared (IR), Raman Spectroscopy and ultraviolet visible (UV-Vis). He suggested that the UV-Vis is suitable for examination of normal ink pen strokes or erasable ink pen strokes (107).

The researchers in this study examined gel pen inks with the help of thin layer chromatography (TLC). A total of 15 black, red and green gel pens of various colours

and brands were collected from local markets in India. About 5 µL of concentrated ink sample was collected from the barrel of the pen and diluted using 50 µL of ethanol. The extracted ink was then spotted on the precoated silica gel TLC plate with the help of fine capillary tubes. The spots were dried for about 10 minutes and were developed using 6 separate solvent systems. The chromatograms were air dried and visualized under visible and UV light (366 nm). The results obtained were then studied based on difference in color and Rf value of the spots under visible light and ultraviolet light. Some ink samples didn't show any movement on plate with any of the selected solvents. Therefore, it was concluded in this study that TLC is a more reliable method to analyze gel pen inks consisting of dyes. The authors also suggested analyzing bulk ink to achieve better results (108).

The researchers developed a non-destructive method which is economically viable, rapid, eco-friendly and portable method to decipher thermal ink writings on different varieties of papers and surfaces with the help of Video spectral comparator VSC-6000/HS. Detection of ghost strokes under the spotlight of VSC and specific UV range between 312–365 nm provided a new avenue by which the document examiners could analyse and examine the erased writing accurately (109).

The study suggested a methodology to differentiate ball pen and non- ball pen inks with the help of high-performance thin layer chromatography (HPTLC). The effect of environmental factors on chromatograms was also studied. A total of 3 blue pen inks and 9 blue ball point pen inks were examined in liquid and in dried-paper form. The chromatograms were visualized under visible and ultraviolet (UV) light. A comparison was drawn between the HPTLC chromatograms of exposed and non-exposed chromatograms. It was found that exposed chromatograms of ball pen inks had some bands missing. This could be due to the evaporation of volatile components and solidification or polymerization of resins which results in the retention of pigments on the paper. The case was contrary in exposed ball-point pen ink chromatograms. Few additional bands of low intensity were found in exposed ball-point pen ink chromatograms. These additional bands were degraded products of dyes produced by UV radiation. The intensity of bands was generally low due to the demethylation process. It was concluded that inks undergo chemical changes with the time and under

various environmental conditions. HPTLC was found to be an efficient, reliable and affordable technique to examine ball pen and non-ball point pen inks (110).

The researcher studied ballpoint pen inks using different techniques. A total of 15 green, 24 black, 21 red and 18 blue ballpoint pen inks were collected and examined by five different methods i.e. thin layer chromatography (TLC), Raman spectroscopy, visible spectroscopy (VIS), Fourier transform infrared (FTIR) and filtered light examination (FLE). The results of all the mentioned techniques were compared in terms of their discriminating power. It was found that the non-destructive technique FLE showed highest discriminating power (0.94-0.99) for green, black and red ink ballpoint pens. On the other hand TLC showed best results for blue ink ballpoint pen (111).

In this study, the researchers discussed various analytical techniques employed for the characterization of ink. TLC was found to be the easiest, simplest and vastly used technique for the analysis of colored components (dyes) of inks. Its use for the analysis of different ink types by various authors was discussed in detail. Gas chromatography-mass spectrometry (GC-MS) was outlined as another effective and reliable method for the examination and analysis of non-colored components (volatile) of inks. Different sampling methods for the extraction of volatile components from inks were used such as liquid-liquid extraction method, head space (HS) extraction method and direct thermal desorption method. It was suggested that the future work should be done on the analysis of different ink types isolated from different substrates (112).

In this study, the author analysed that often the questioned documents received by forensic science laboratories face handwritings that intersect with stamps, typewriting, intersection strokes, background etc. The fine details of the word or letter such as beginning, ending could be examined or determined. This paper proposed various new digital photography techniques that can reduce the effect of these intersecting lines. This method was also considered inexpensive and fast (113).

The study carried out an extensive research on the impact of different grades of solvent systems on the analysis of ball point and non-ball point writing inks with the help of thin layer chromatography (TLC). About 50 ink samples (26 ball point and 24 non-ball point) were collected from the United States Secret Service (U.S.S.S) international ink

library in the form of written ink lines or smears placed on reference sheets. The number of punches required for examination depends on the degree saturation of ink on the reference samples. Sample preparation was carried out by dissolving ball point pen ink punches in pyridine (5-10µL) and non-ball point pen ink strokes in ethanol: water (1:1) (5-10µL). The chromatograms were analysed under visible and ultraviolet light. Three document examiners verified the results. Each examiner graded the plates from 1 to 3 on the basis of separation and clarity of the dyes on the chromatograms. The denatured grade ethanol, HPLC grade water and ACS grade ethyl acetate showed excellent separation of dyes. Unlike solvent system 1, it was impossible to access the best grade of solvent system 2. Factors such as relative humidity, pH of silica gel and amount of extracted dye/pigment could have also affected the results (114).

The researchers in this study discussed an effective process to discriminate inks with the help of microscopy, thin layer chromatography (TLC), liquid chromatography tandem mass spectrometry (LC-MS/MS), video spectral comparator (VSC) and gas chromatography-mass spectrometry (GC-MS). A total of 18 blue ball point pen ink samples were gathered from domestic and foreign brands and used to draw ink lines on A4 sheet (80 g/m2). The coloured component of ink was examined with the help of TLC whereas the non-coloured component was examined using GC-MS. The bands showed differences in the intensity because of the uneven concentration of dye that are extracted from ink samples. The chromatograms were visualized under visible and ultraviolet light and categorized the 18 inks into 12 groups. No interference was observed from paper blank. Identification of components was carried out through National Institute of Standards and Technology Library (NIST) library of GC-MS. 18 inks were classified into 9 groups on the basis of components identified through GC-MS. Both TLC and GC-MS were found efficient to differentiate ballpoint pen inks (8).

The author of the study analysed blue ink ballpoint pen of 5 different brands which were mostly used across India. Samples were collected from 2 models of each inks on paper surface. TLC (Thin Layer Chromatography) and paper chromatography was used to analyse the samples of writing ink. This research was carried out to examine the separation of blue ink samples of 5 different brands. A reference sample was also used to compare with the results. Ink of blue ballpoint pen was examined to study several

properties like composition of different inks, separation of ink of different brands of pen, different batches and different models. The study concluded that TLC (Thin Layer Chromatography) is the most effective and reliable technique for the examination, analysis and ink separation (115).

The researchers discussed a prototype with the help of a simple mathematical arrangement of the pen pressure data recorded by a digital pen movement recording device. In order to compare the pen pressure data they use Pearson's correlation coefficient. The prototype can be considered as a supporting technique which in result can also enhance the objectivity of examination of various signatures. This in result can also be used as a tool for automated signature identification. Pressure pattern graphs allow us to establish a relationship between peak and stroke segment which in result allows the comparison of signatures with variation in structures. This present study helps in determining the degree of similarity between two signatures by using Pearson's correlation coefficient. This method can be utilized to rule out the common authorship and also in the identification cases (116).

According to the study, the researchers studied various techniques used for the identification of ink samples in the laboratories. It was reported that both TLC (Thin Layer Chromatography) and HPTLC (High Performance Thin Layer Chromatography) were the most widely used techniques for ink analysis in forensic science laboratories. Stamp pad inks, ballpoint pens, roller tip pens etc. all were examined using either of two techniques (117).

In this experiment, the researchers studied ballpoint pen inks with the help of HPTLC (High Performance Thin Layer Chromatography. A total of 57 ball-point pens of blue ink were gathered from local markets across north India.. The chromatograms obtained were visualized in visible and ultraviolet light. TLC scanner 4 was used in the measurement of absorbance of bands at 580 nm. Win Cat software was used for recording the spectra, detection of peaks and documentation of data. Most of the ink samples consisted of pink, violet, blue and yellow colour bands. Crystal violet was found as a major dye among ink samples. The evaluation of the result was based on the number of bands and Rf value. The ink samples were grouped into 5 classes depending

on the basis of the number of bands. The ink samples with a similar number of bands were further classified on the basis of Rf value. The overall potential of HPTLC to discriminate ballpoint pen inks was found to be 93.80%. The reason stated for low discrimination was due to the fact that HPTLC analyses only dye components. Other techniques like attenuated total reflection-fourier transform infrared spectroscopy (ATR-FTIR) were suggested in addition to HPTLC for better results. The HPTLC proved to be a reproducible, cost effective and reliable method to analyze ink samples (118).

The authors of the study discussed that conductive inks that are based on carbon black and graphite were utilized in a wide range of applications like printed heater, energy storage, electrochemical sensors and energy harvesting. Different concentration of carbon black, vinyl polymer and graphite is used to prepare screen printable carbon inks. They are printed to establish different effects on deposition, conductivity and rheology. It was found that at a graphite to carbon ratio of 2.6 to 1 optimal conductivity is achieved, at a carbon loading ink of 29.4% by mass (119).

The researchers in the study examined the growing cases of secret writings and suggested that secret ink writing is the skill of concealed writing. This art of secret ink writing is focussed to remain unreadable for the other readers, and only be visible for the person to whom the message was written. Secret writing samples with hidden massages are usually prepared using fruit juices, biological fluids, chemical fluids, etc. The samples were examined physically and chemically for one month with a regular interval of five days. The study concluded that the heating and iodine methods were the best among the physical and chemical methods to visualize the invisible writings (120).

The study involved the use of Raman spectroscopy for ink analysis due to its speed and sensitivity. Sample preparation is not required for this technique. It is a non-destructive technique. However, there are some limitations too, such as the overwhelming phenomenon of fluorescence and low sensitivity. But these factors can be controlled using resonance and surface-enhanced Raman Spectroscopy (121).

The researchers performed a comparative study between erasable and disappearing inks. It also aimed at finding out their roles in different cases of fraudulent documents. The results provide the difference between both types of invisible ink i.e. erasable and

disappearing which helps the forensic document examiners in dealing with them appropriately in different court cases. Phenolphthalein containing disappearing ink is found to lost its colour faster than the one containing thymolphthalein. When exposed to U.V. light the colour of disappearing is changed. It was also found that erasable ink is not absorbed by the paper instead they remain on the surface but unlike erasable ink, disappearing ink is absorbed by the surface of paper. Both types of invisible ink erasable as well as disappearing were found to be more stable on polycarbonate polymer sheets (106).

The study reported that precision and accuracy rate of multivariate methods of analysis have raised demand in the field of forensic sciences. This study is focused on the 3 important aspects. Firstly, characterization of inks of marker. Secondly, to differentiate between inks of whiteboard marker and permanent marker by using both destructive as well as non-destructive techniques. Different methods were used like chemometric methods, UV-Vis absorbance combined with examination of peak identification. Thirdly, to build a method for classification of inks of whiteboard marker and permanent marker. It was found that chemometric methods was best as compared to other methods and give better power of discrimination (12).

In the study, the researchers reported that gel pens are available in a variety of colours and they are composed of water-based ink containing either dye or pigments. Different analytical techniques were used, among which Raman Spectroscopy was found to be most useful as it provides better ability to distinguish gel pen inks based on different types of pigments. This technique can be performed in situ. In this technique a laser of specific wavelength is directed onto a sample of ink to detect scattered light which results in generation of molecular structure characteristics. It provides a molecular fingerprint for the purpose of comparison. Different excitation wavelengths can be utilized to get different spectra of a particular sample of ink (122).

The experimenters in this study prepared disappearing ink from thymolphthalein. It was found that VSC-8000 can decipher vanished writings under UV range of 254 nm exposure.. Disappearing ink writings was found to be easily decipher by using NH3 vapour. This chemical method is very useful to detect disappearing ink residues without harming the document (123).

The authors in their research reported a new technique for sampling capillary electrophoretic analysis of inks used for writing directly from the paper surface. A sample is taken by cutting a piece of paper having a word written on it, this piece of paper is then placed on the sampling platform. Now an automated system is utilized to solubilize the ink from the sample by depositing about 3 µL of background electrolyte onto the piece of sample containing the writing. This solution is analysed by injecting the small portion into the capillary electro-kinetically. The consumption area of the ink surface was about 40x less than the convention technique of off-line extraction of sample. The higher analytic solution concentration results in injection of less sample volume into the capillary which results in high signal-to-noise ratio (S/N) and better shape of peak (124).

In this study, the researchers worked on examination and comparison of fountain pen inks and examined different kinds of pen inks. In the study inks were discriminated through UV-Visible spectroscopy, TLC and FTIR spectroscopy. TLC differentiated the coloured components of the ink and the absorption spectra of FTIR differentiated the functional groups of other inks. The combined results obtained from TLC, UV-VIS and FTIR leads to found DP from 0.80-1.0 for black, 0.5-1.0 for green, 0.73-0.8 for blue, and 1.0 for red coloured fountain ink pens (125).

The experimenters in their research tried to differentiate various types of black and blue erasable ink gel pens. For this purpose, they undertook various techniques like Fourier transform infrared analysis, micro-spectrophotometry, infrared visual analysis and fluorescence. The outcome of this research showed that FTIR, IR visual and fluorescence can better distinguish various types of erasable ink gel pens. On the other hand, micro-spectrophotometry can be effectively used to differentiate blue erasable ink gel. It was suggested to use all these four analytical methods in combination for accurate and better results (142).

In this research, the authors focussed on preparation of disappearing ink by using O-Cresolphthalein and Thymolphthalein in different concentrations. Different varieties of papers were used for this study. The result showed that the stability of handwriting is increased when concentration of O-Cresolphthalein and Thymolphthalein is increased.

When an alkaline solution was applied to the faded writings, it became visible. The study also concluded that temperature has no effect on the faded writings (143).

The researchers in this experiment analysed to find out a new detection method for the examination of obliterated writings written with the same instrument. Different samples were carefully prepared by using physical and chemical erasures on different varieties of paper. Visual Spectral Comparator -6000(VSC) was used to decipher the obliterated writings. It was found that Multispectral imaging on VSC can be effectively used to detect obliteration made with the same colour ink (144).

The author of the study demonstrated the effect of temperature on thermal erasable ink on different varieties of papers. The study involved different varieties of heat sources. It was found that thermal ink disappeared when heat was applied at a specific temperature and it became visible at low temperature. Different properties of thermal ink were discussed in this research (145).

Literature reviewed so far concludes that ink can be efficiently analysed to prove the authenticity of the documents. One can examine and find out whether one or more types of ink are used in a given document or not. Different physical and chemical examination methods are available to differentiate combinations of ink. Various instruments like TLC, HPTLC, VSC, GC-MS, etc. are there to determine the composition of ink. It was found that different types of inks are available. Invisible ink is now widely used by forgers for committing various crimes.

Objectives of this research:

Research and Development in the field of science and technology has led to the advancement of both the directions i.e. positive as well as the negative. In the field of Forensic Science, the scientists working in the laboratory are continuously dealing with the new type of frauds. Criminals are adopting new modus operandi with the new technology to cheat and fraud the individuals. One of the latest tool used by criminals to commit forgery with the bank instruments (cheques or other withdrawal form) or with other paper documents is the use of invisible ink pens. The two varieties of invisible inks are, erasable ink which can be erased easily by applying heat and another type is disappearing ink which becomes invisible to the naked eyes with the passage of time. They are cheap and easily available forgery item. In these types of cases, the forger extends help to the person in filling out the bank cheque or other different forms like withdrawal form to withdraw the money. By some trick, the culprit give the disappearing ink pen to that person to fill the bank cheque but is smart enough to get the signature with the normal ink pen. In few cases, the forger or the culprit breaches the faith of a known person by filling out the main body of the cheque with the disappearing ink pen and gets the signature of that known person with normal ink pen. The invisible ink either erasable or disappearing became invisible, so the forger are able to re-write over the main body of the cheque with the normal ink pen, thus manipulating with the bank related documents and cheating the percent who is innocent, therefore this study entitled **"Decipherment of Invisible Ink Through Various Techniques"** has been carried out to develop a simple and rapid technique to decipher disappeared writing on the documents related to financial and various other crimes with the following objective:

The aim of this present study is postulated in 3 objectives:

1) **To determine the effect of temperature on invisible ink**

2) **To restore the invisible writings through various techniques**

3) **To detect the alterations in paper due to erasure**

CHAPTER – 3

TO DETERMINE THE EFFECT OF TEMPERATURE ON INVISIBLE INK

3.1 Introduction:

Invisible ink is prepared by special chemical reactions carried out generally for industrial purposes. Invisible ink pen looks like any other pen available in the market but it has different chemical composition. It is commonly known as magic pen. Auto-disappearing inks can be easily found in the market which raises a great deal of concern (123). The main two varieties of invisible inks are disappearing ink and thermal ink. Disappearing ink is a combination of different chemicals which causes the ink to become visible for a very short duration of time, following which it disappears. It works on the principle of acid/base chemistry and is an irreversible reaction (143).

Thermal ink is also popularly known as thermochromic ink. It can be defined as a type of erasable ink that can be easily removed by creating friction by the eraser that comes with it (87,125). It comes in various colours such as blue, red, black and green. Thermal inks can be readily removed from the paper surface by exposing it to heat and then cooling simultaneously. The ink is viscous in nature and it largely depends on the heat produced during erasure which is known to affect the solvent of ink. The fading of thermal ink works when there is an external heat factor such as friction created or applied due to erasure of the pen or by direct exposure to heat.

These inks are widely used in false practices involving criminal activities. Criminals use thermal ink pens to erase the original writing and then rewrite with the intent to defraud. Such obliterations are not visible to the naked eyes and are difficult to detect. Forensic document examiners are familiar with vanishing inks but the general public is not at all educated of these malpractices. These inks are easily available in markets across the globe. One such example is, ‘Replay’ which is a thermal ink developed by ‘Paper Mate’ company in the United Kingdom. Pilot company manufactures the most common type of erasable pens under the name 'Frixion'. It comes along with an erasable rollerball pen (93).

These pens come up with an eraser fitted at the top of the pen which can be used to erase the writing. It is worth noting that while removing the ink with an eraser fitted with the pen, small traces of writings can still be visible to naked eye. Due to the action of the eraser on the paper, it generates heat due to friction and results in decolourization of the ink lines but does not scrape it away (146)

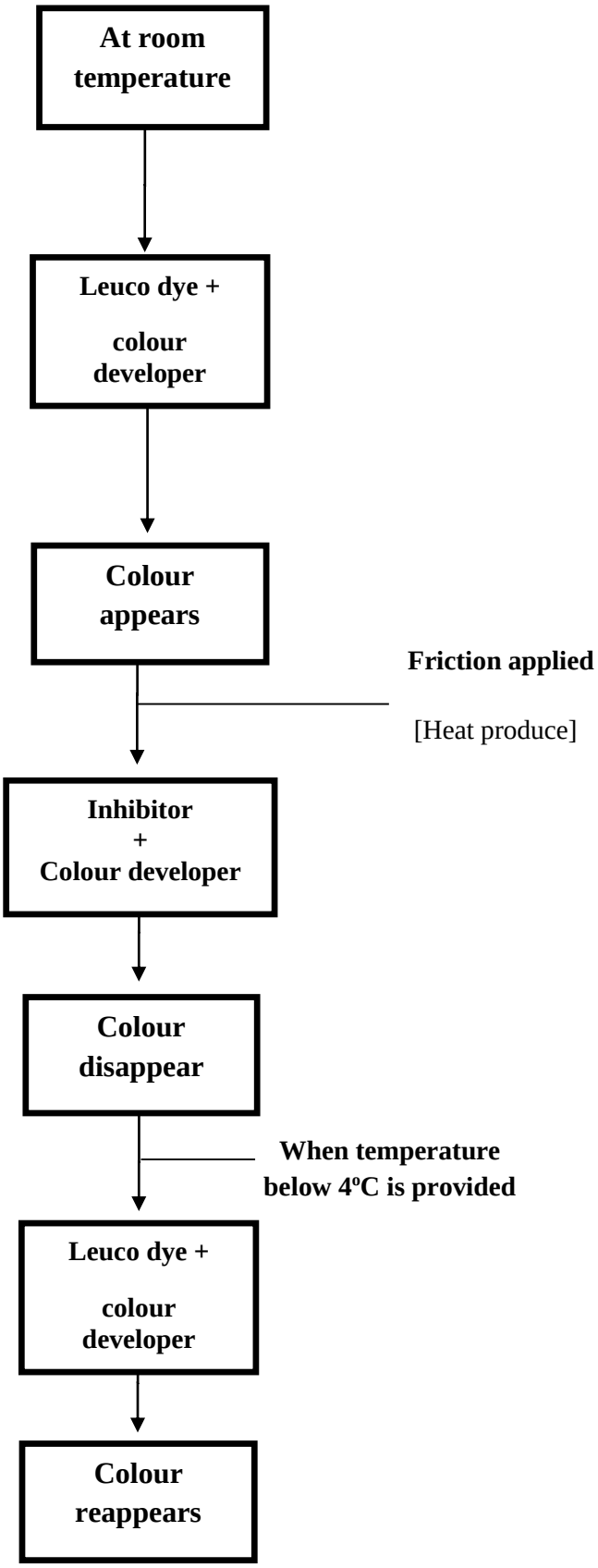


Figure 3.1: Flow chart showing how Erasable Thermal Inks works

Pigments that form microcapsules are composed of primarily three components: leuco dye, colour developer and temperature regulator. Leuco dye has the ability to switch between coloured and colourless forms. Colour developer reacts with leuco dye and makes a chemical bond that results in colour formation. The third component is a temperature regulator which undergoes colour change according to the temperature. The leuco dye is the main component which determines colour, but it needs to chemically bond with the colour developer to produce colour. There are certain factors that prevent the bonding of leuco dye with the colour developer. One such factor is an inhibitor that inhibits the bonding between the two components above a particular temperature, hence resulting in colour disappearance. There are various temperature regulators present that can be employed to regulate colour change at different temperature (147).

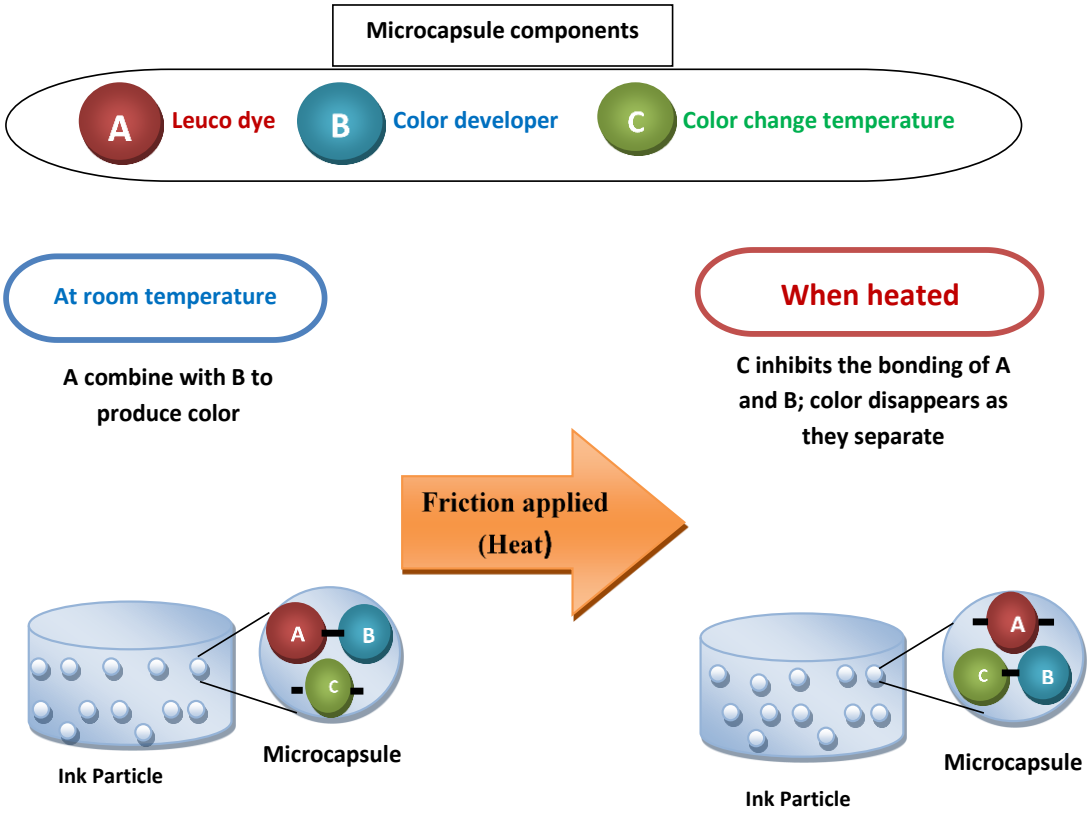


Figure 3.2: Reaction of Thermal Ink

The Leuco dye developer system is the solvent system employed in thermal inks. Leuco dye (colour former) when it interacts with the developer it results in the formation of the 3 different components responsible for colour change. The most commonly used

colour former is Spironolactone molecule. Lactone has ring openings which give colour to CVL (Crystal violet lactone) due to increased conjugation or hydrogen bonding nature of the developer. Phenols are commonly used as colour developers. There are various solvents available in the market which is commonly used in the inks, such as esters, acids having long chain aliphatic character, amides or alcohols (148).

According to the literature thermal erasable ink disappears at around 60^{o}C and again reappears at around 4^{o}C or below.

3.1.1 Properties of thermal ink

It is found that erasable inks show sensitivity towards acid-base which can be tested when 3M HCL or 3M H_2SO_4 is added to dry erasable ink at low temperatures. When the two react, it forms a pattern of colour spreading on the paper that helps keep their colour at high temperatures. When acid is added to the same dry ink after conversion at high temperature, it reverts back to the coloured form. But, when 3M NaOH or 3M NaCl is added, it shows little to no effect on the behaviour of ink at high and low temperatures (149).

Upon examination under optical microscopy, granular structure of ink can be found which could be a result of micro-encapsulation. Majority of these granules are of the size 1-2µm and it can go up to 8µm. Generally, the aqueous solution does not impact the structure of the ink granules. However, in some cases it is observed that the acid-base reaction can affect the structure of the ink granules by penetrating the granules.

Various components of the ink thermodynamically reach their coloured form at low temperature, and become colourless at high temperatures. It is to be noted that when differential scanning calorimetry (DSC) is heated at 57°C - 60 °C (without any exothermic transition in the given range) on black Frixion ink, it shows a dominant endothermic transition.

Upon cooling, the dominant endothermic transition happens at around −3°C - 0 °C (without any endothermic transition in the given range). These temperature ranges were found to be consistent for wet ink, dry ink, and aqueous solution inks when HCl, NH3 or NaOH is added (150).

Different forms of ink components can coexist at room temperature when provided with a sufficient activation barrier. This situation can be defined as the colour hysteresis (131). It

was found that α-anthracene terminated methoxy polyethylene glycol (An-PEG) aqueous solution can be used as a new type of ink to be written on conventional paper.

3.2 Methodology:

3.2.1 Materials used:

1. Blue, Black & Red erasable ink pen of 3 different brands: Pilot, Hamley Hamster & Yes office solutions
2. Three variety of papers: White Copier paper (70gsm), Bond paper (90gsm) and Glossy paper (180gsm)
3. Havells Iron (1000W)
4. Phillips hair dryer (1800W)
5. Domestic refrigerator(Whirlpool)

3.2.2 Sample preparation:

- There are total 810 samples recorded, 270 samples for each pen brands. In this study 3 ink removing methods i.e. erasure available at the backside of each pen, hair dryer and domestic iron methods are used on 3 different paper types mentioned above.
- A total of 10 samples were collected for each paper type and removing method for their respective colour pen type.
- Observations were made by using a hand magnifying glass and unaided eye.

Figure 3.3: Invisible ink pens used for sample preparation

3.3 Observation and Result:

Thermochromic ink pens are incorporated with an erasure at the tip of each pen which can be used to generate heat through friction which in turn decolourize the ink lines. This erasure can affect the physical properties of the paper depending upon the quality and type of the paper used.

We used three methods to remove thermal ink from the paper. Firstly, Physical erasure incorporated at the tip of each erasable pen.

Secondly, we used a domestic hair dryer (≈80^{o}C) to remove the writings made by thermal ink pen. It takes only 1-2 minutes to remove writings from the paper. It was observed that the colour of the ink reappears in specific region of page with the movement of air stream (148).

Domestic iron at a moderately hot, "two dot" (≈105^{o}C) setting was also used to remove the thermal ink writings. To protect the study paper, another sheet of paper is placed above the study paper before using the iron. The same effect was achieved when "one dot" (≈76^{o}C) setting of the iron was used to apply heat (148).

Sample made by disappearing ink was also analysed to check the effect of temperature on disappearing ink.

All the samples with decolourized writings were placed in a domestic refrigerator (low temperature) to restore the writings. The temperature of the refrigerator was measured and set to -4^{o}C. Following results are observed:

Table 3.1: Observations obtained by Refrigeration method

OBSERVATION TABLE											
S.No	Pen Brand	Type of Paper	Blue Pen			Red Pen			Black Pen		
			Ink Removing Method Used								
			Pen Erasure	Hair Dryer	Iron	Pen Erasure	Hair Dryer	Iron	Pen Erasure	Hair Dryer	Iron
			Reappearing time at -4°C (in minutes)								
1	PILOT	Copier	20	20	20	20	20	20	20	20	20
		Bond	20	20	20	20	20	20	20	20	20
		Glossy	-*	20	20	-*	20	20	-*	20	20
2	HAMLEY HAMSTER	Copier	1	1	1	1	1	1	1	1	1
		Bond	1	1	1	1	1	1	1	1	1
		Glossy	1	1	1	1	1	1	1	1	1
3	UNIBALL	Copier	10	10	10	10	10	10	10	10	10
		Bond	10	10	10	10	10	10	10	10	10
		Glossy	2	2	2	2	2	2	2	2	2

*only traces at the end of strokes becomes visible.

Above table explains the reappearing time of the erased writings when placed at -4°C in a refrigerator. It was observed that writings of Hamley hamster pens reappeared quickly (within 1 min) when kept in a refrigerator. On the other hand Pilot pen writings took the longest time (around 20 min) to reappear. Uniball brand writings took 10 min. to reappear when copier paper and bond paper was used. but when glossy paper was used yes brand writings reappeared quickly within 2 min.

It was also observed that few samples doesn't give positive results. In the case of the Pilot pen when a friction erasing method was used to remove ink lines from the glossy paper, it was observed that even after keeping it in a domestic refrigerator for sufficient time, the writings doesn't reappear. Only traces at the end of strokes reappeared.

On the other hand when ink lines of Pilot pen were removed by using hair dryer and domestic iron then it reappeared within 20 minutes when kept under the refrigerator.

3.3.1 Results on Copier Paper:

Copier paper also called as printer paper is the most common paper used to prepare various types of documents. It is thin, opaque and very light in weight. It doesn't have a smooth surface instead it has a matte coating which helps in fast drying.

During the analysis it was observed that the writings on the copier paper reappeared when removed with all the three methods i.e. by using erasure, hair dryer and domestic iron after putting it under the domestic refrigerator. All the three brands used gives the same result in blue, black and red ink on copier paper.

Blue Erasable Ink Samples:

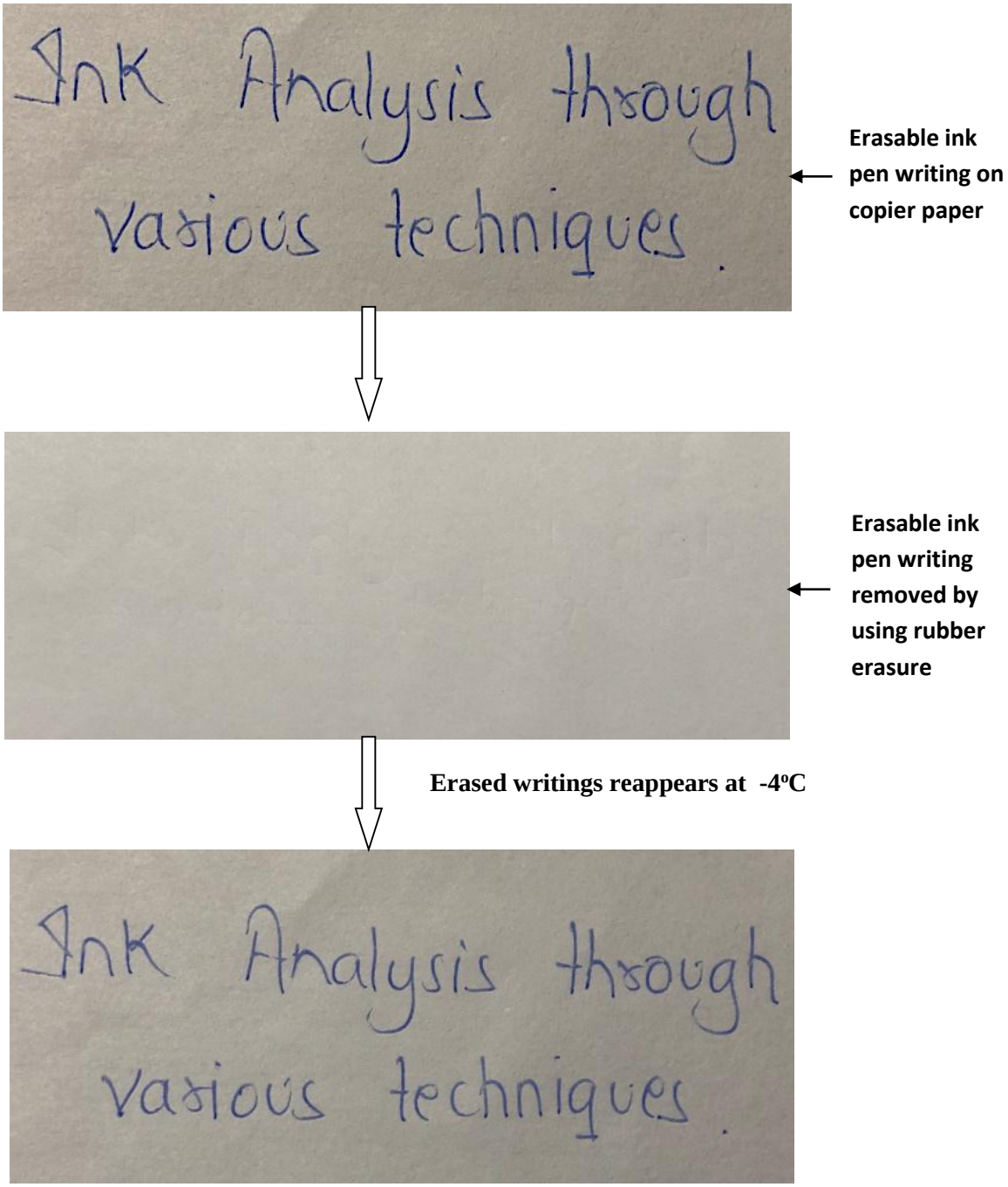


Figure 3.4: Sample of **Pilot BLUE** erasable ink pen writings on **copier paper** reappeared when kept at -4°C.

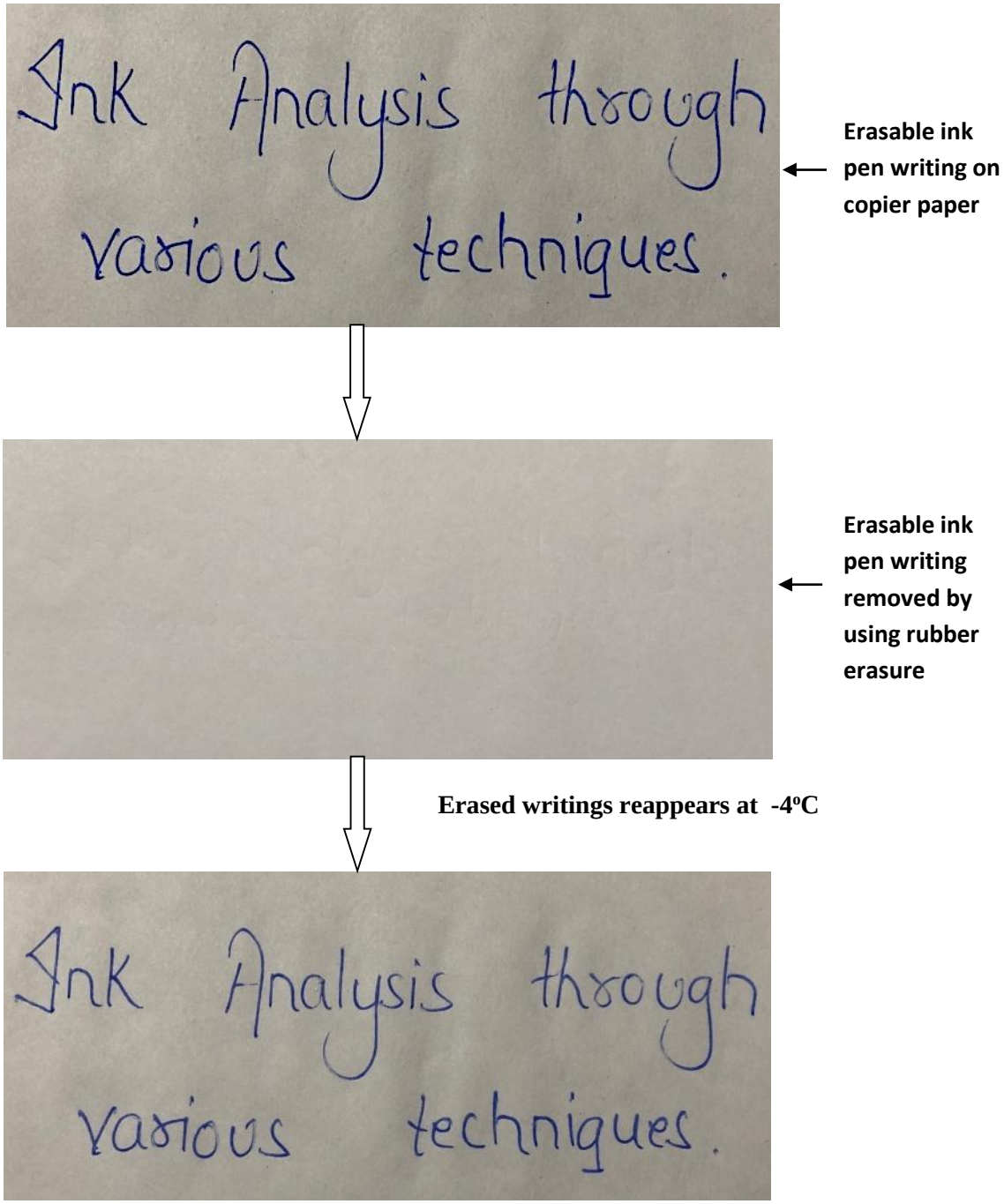


Figure 3.5: Sample of **Hamley Hamster BLUE** erasable ink pen writings on **copier paper** reappeared when kept at -4°C.

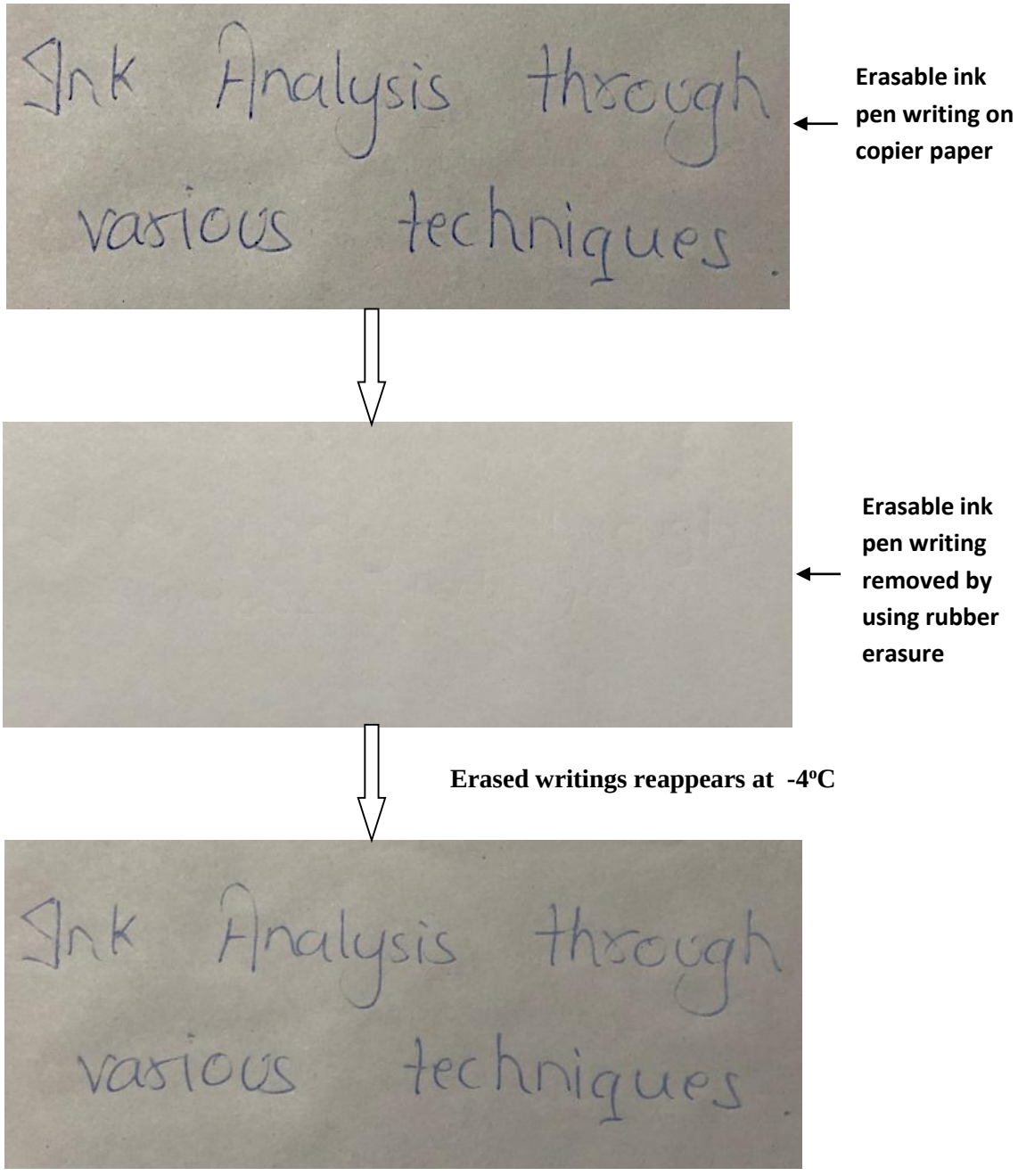


Figure 3.6: Sample of **UNIBALL BLUE** erasable ink pen writings on **copier paper** reappeared when kept at -4°C.

Black Erasable Ink Samples:

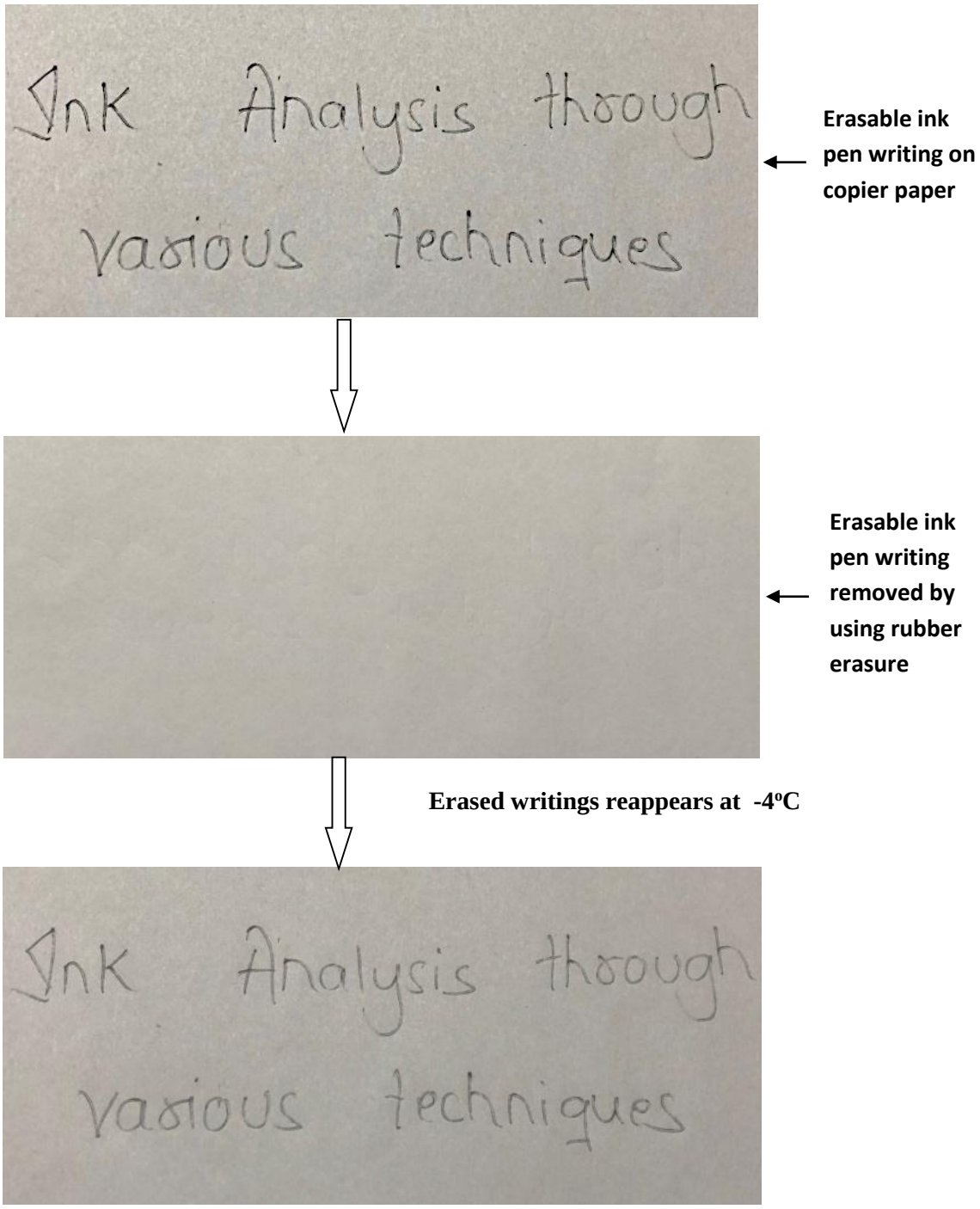


Figure 3.7: Sample of **Pilot BLACK** erasable ink pen writings on **copier paper** reappeared when kept at -4°C.

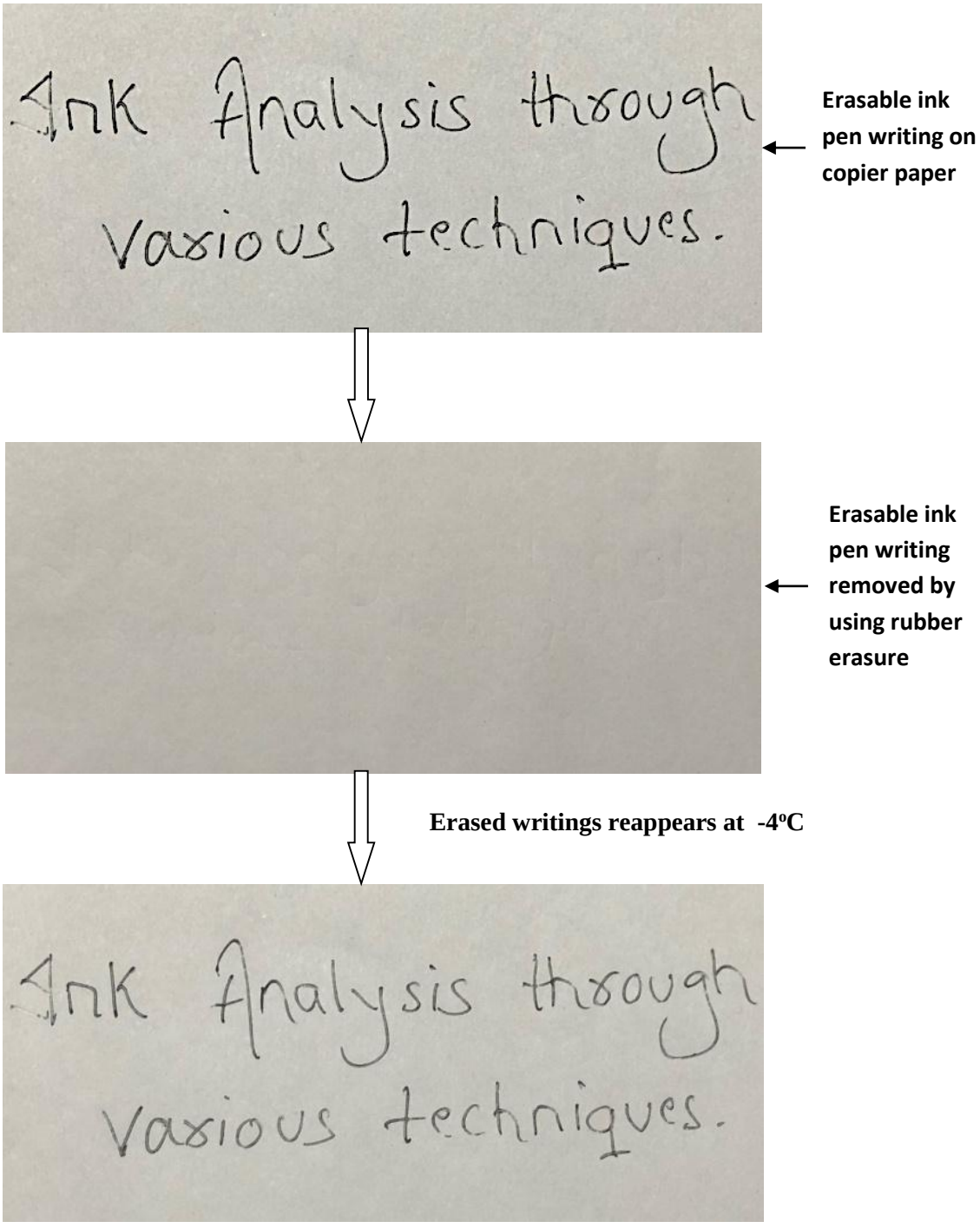


Figure 3.8: Sample of **Hamley Hamster BLACK** erasable ink pen writings on **copier paper** reappeared when kept at -4ºC.

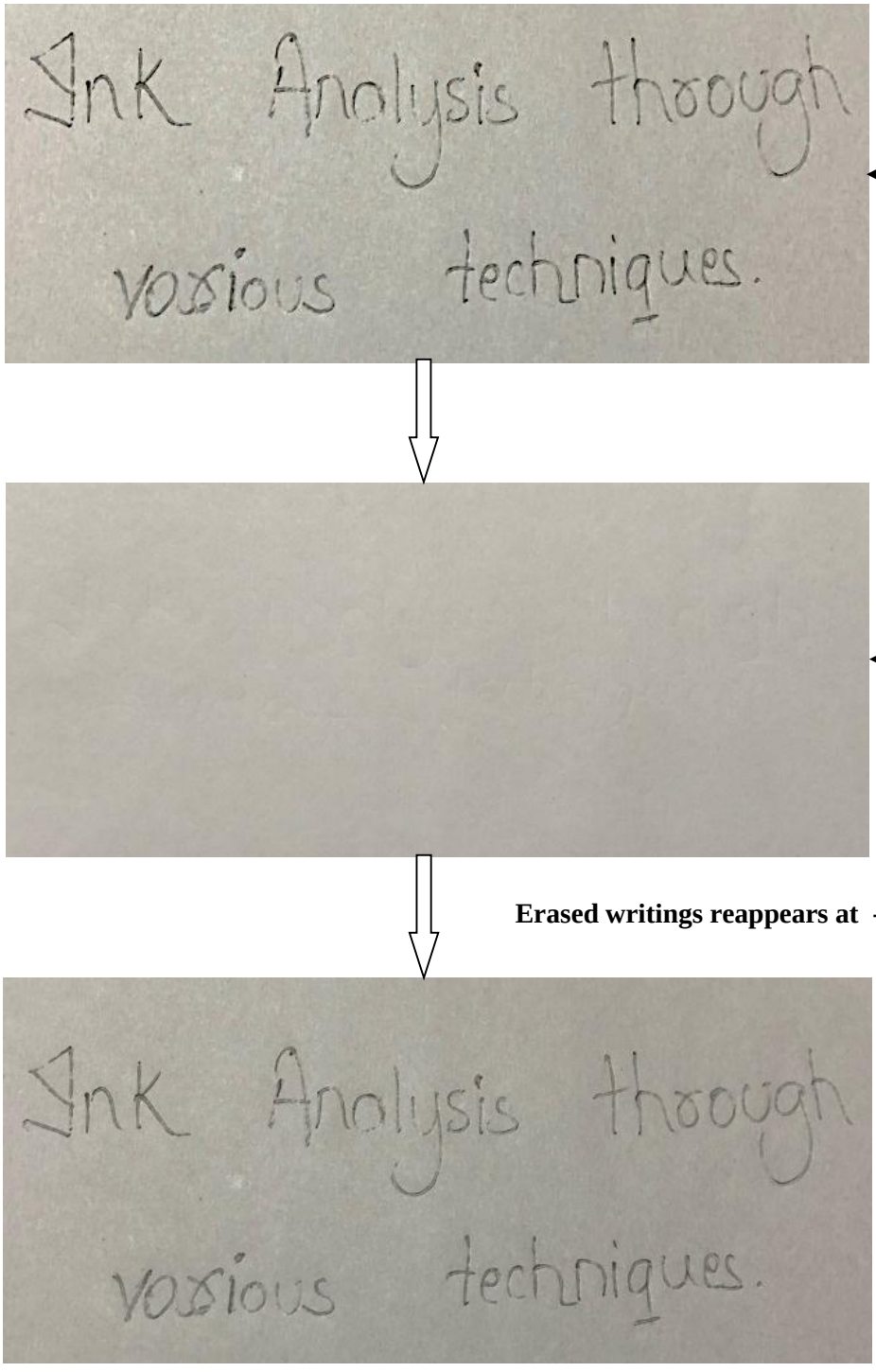


Figure 3.9: Sample of **UNIBALL BLACK** erasable ink pen writings on **copier paper** reappeared when kept at -4ºC.

Red Erasable Ink Samples:

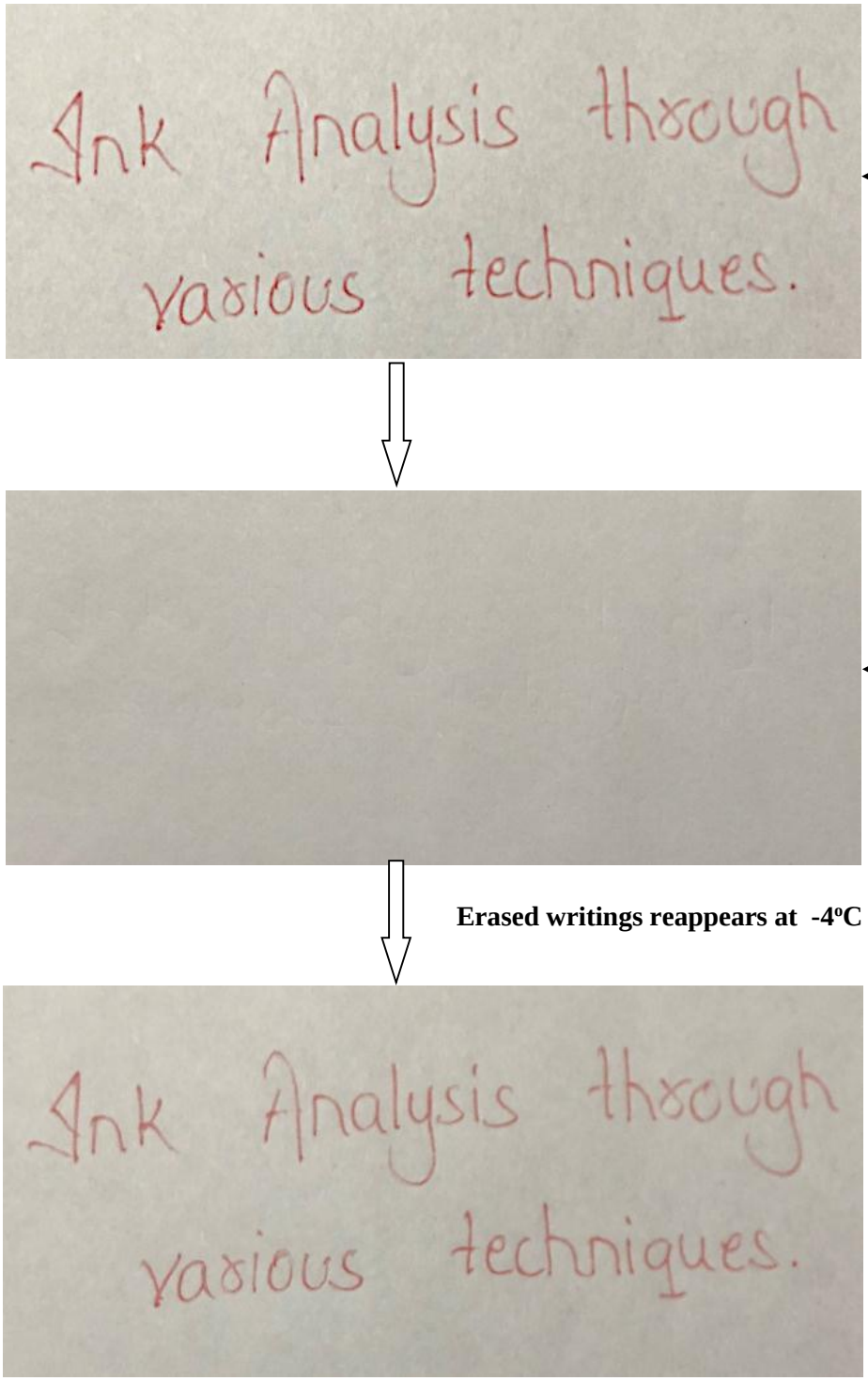


Figure 3.10: Sample of **Pilot RED** erasable ink pen writings on **copier paper** reappeared when kept at -4°C.

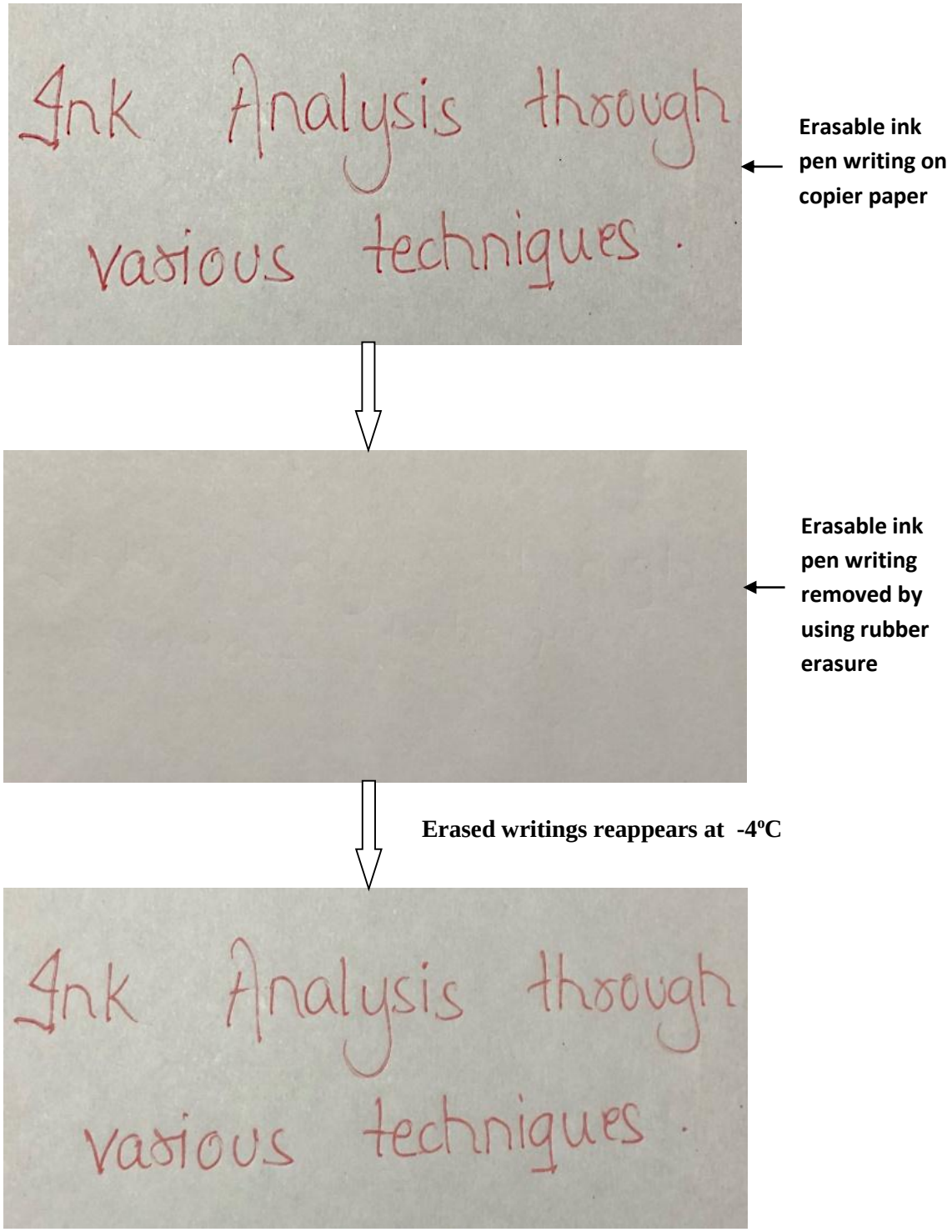


Figure 3.11: Sample of **Hamley Hamster RED** erasable ink pen writings on **copier paper** reappeared when kept at -4ºC.

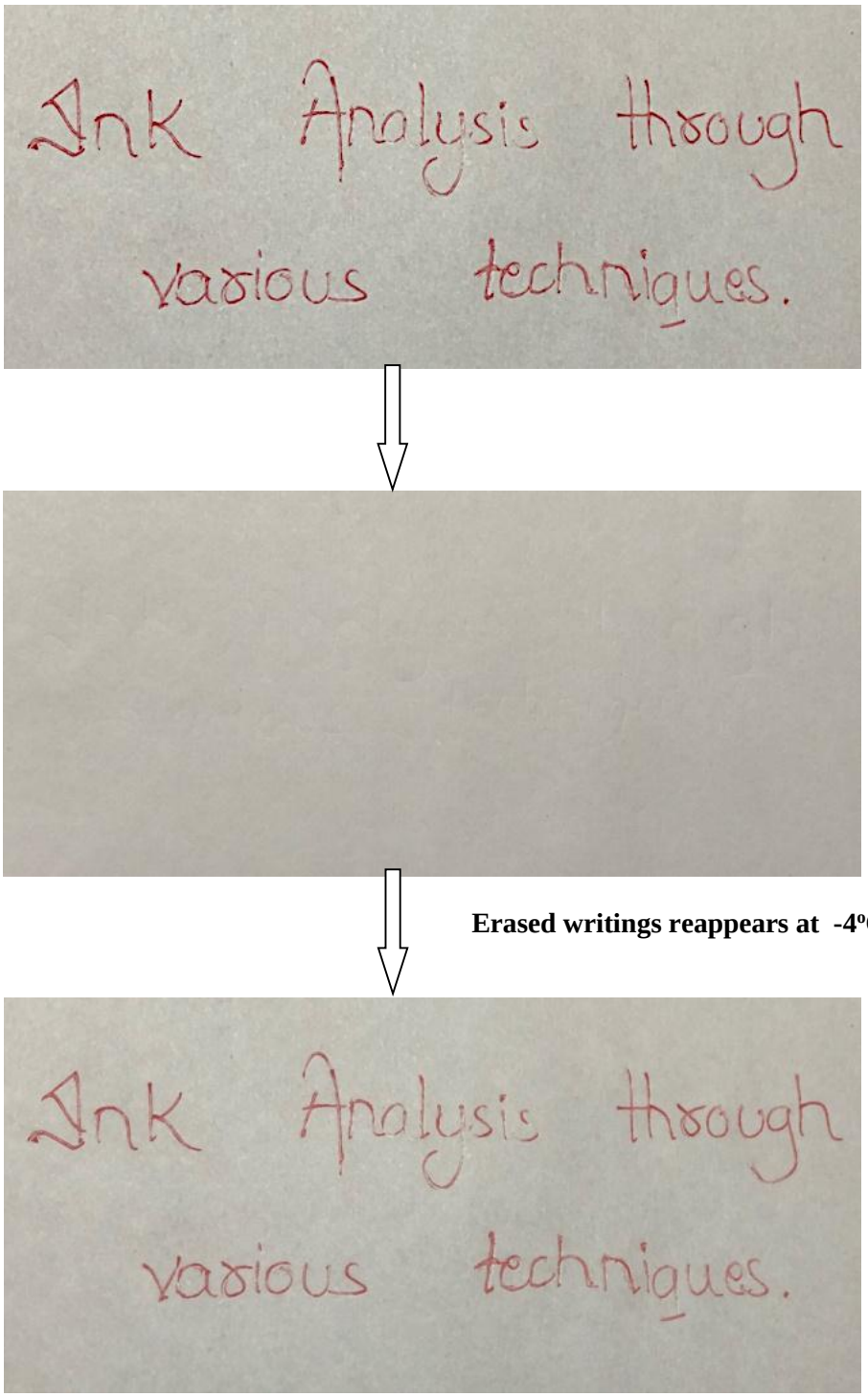


Figure 3.12: Sample of **UNIBALL RED** erasable ink pen writings on **copier paper** reappeared when kept at -4°C.

3.3.2 Results on Bond Paper:

Bond paper is a high quality paper which is more durable than the copier paper. It is available in various range of thickness like 60gsm, 70gsm, 80gsm, 90gsm, 100gsm etc. We used 90gsm bond paper for our research. Bond paper is used to prepare various governments documents and bonds. It is also used by companies to prepare their letterheads. Rag fibre pulp is mostly used to prepare bond paper which makes it more stronger than the normal printer paper.

In our research it was observed that the writings on the bond paper reappeared when removed with all the three methods i.e. by using erasure, hair dryer and domestic iron after putting it under the domestic refrigerator for sufficient time. Similar results are obtained with all the three brands in blue, black and red ink.

Blue Erasable Ink Samples:

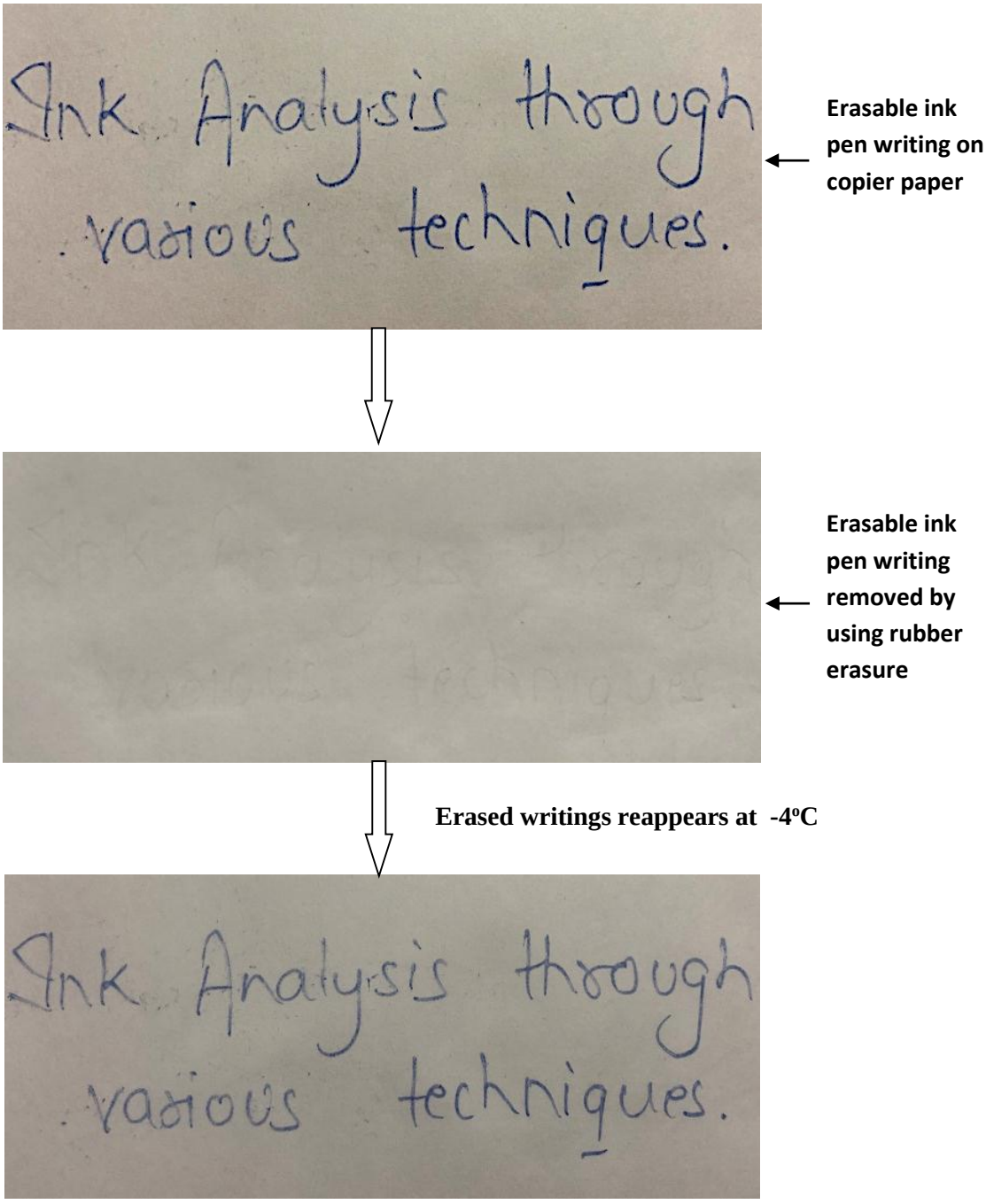


Figure 3.13: Sample of **Pilot BLUE** erasable ink pen writings on **bond paper** reappeared when kept at -4°C.

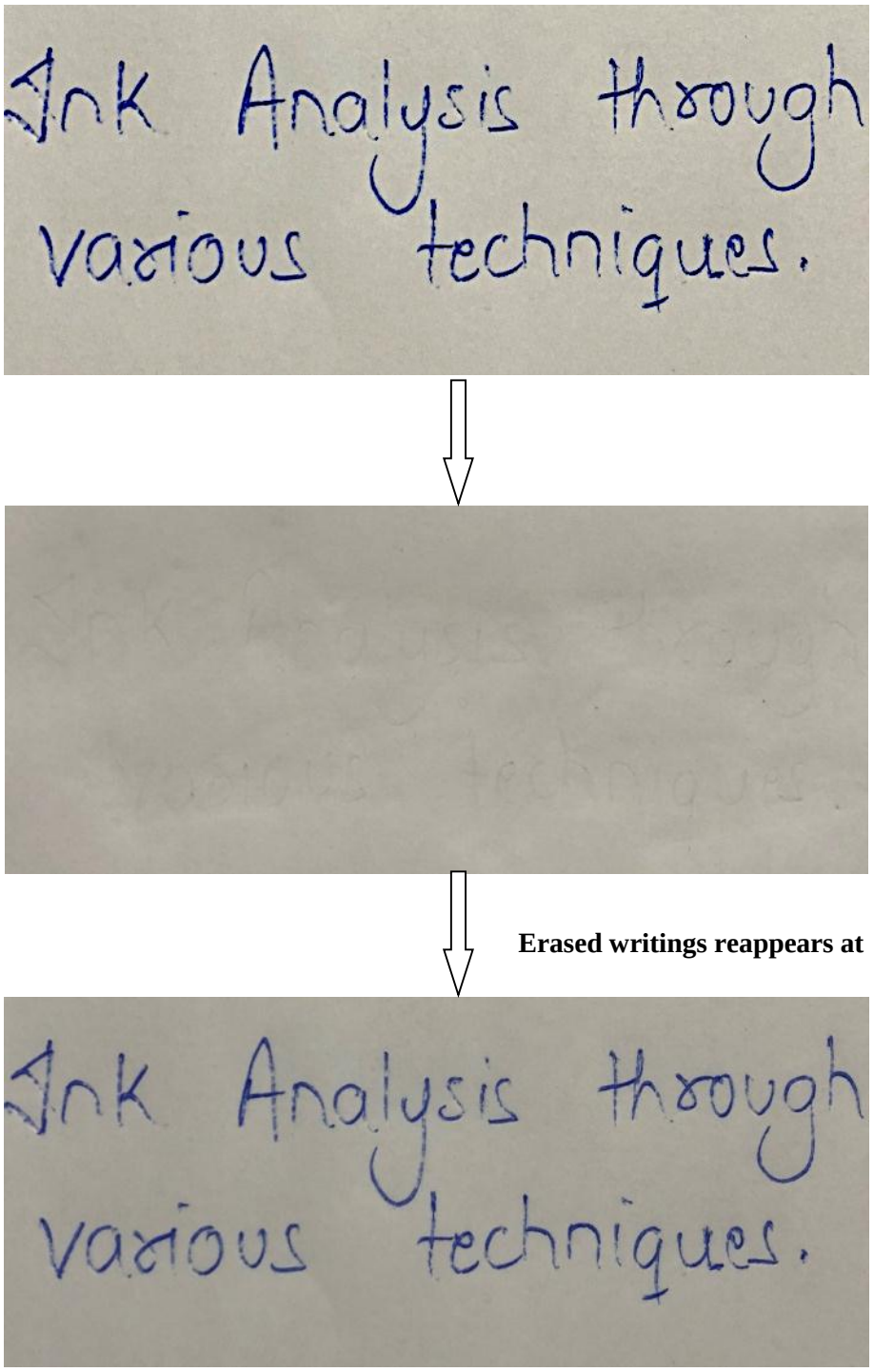


Figure 3.14: Sample of **Hamley Hamster BLUE** erasable ink pen writings on **bond paper** reappeared when kept at -4°C.

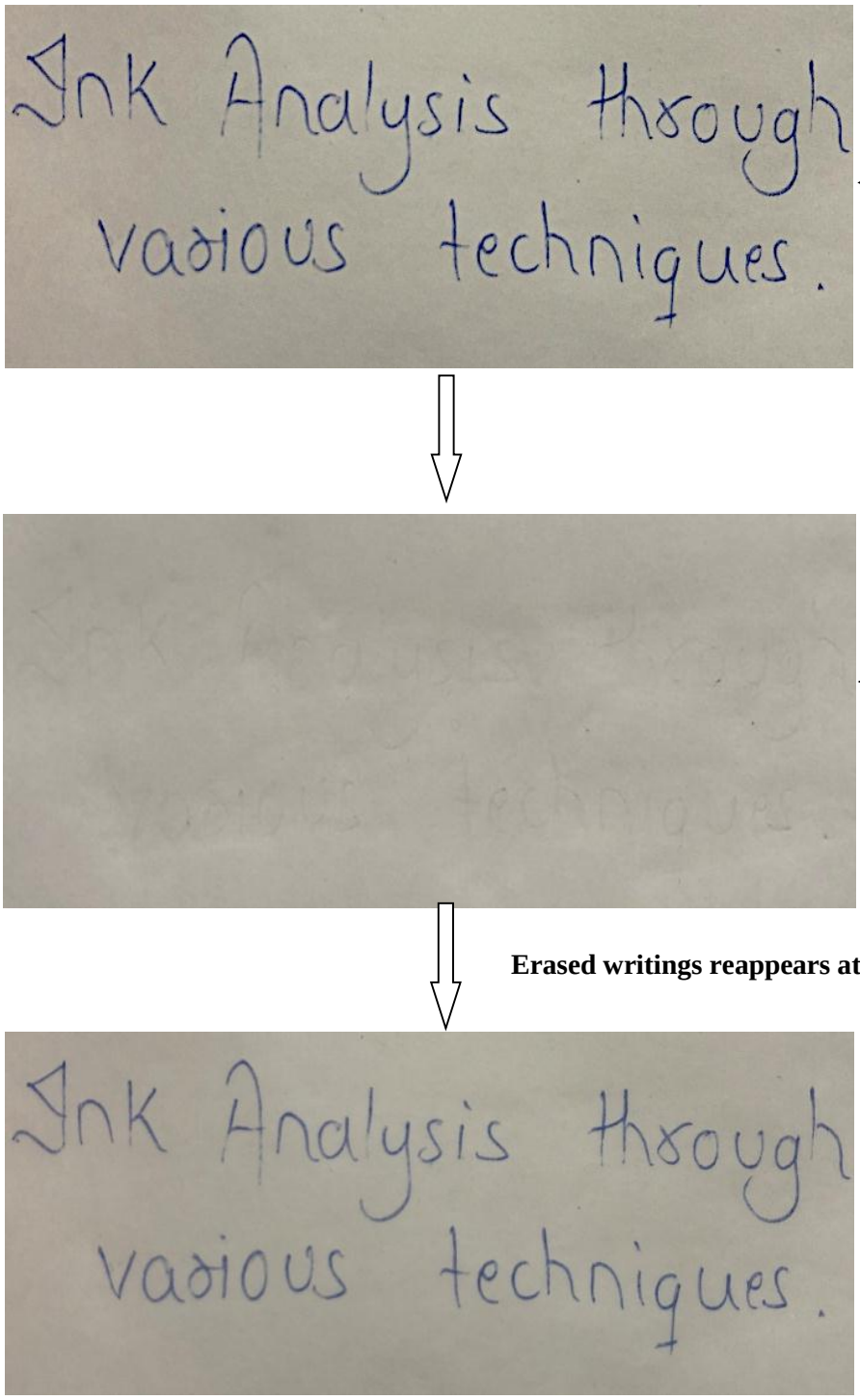


Figure 3.15: Sample of **UNIBALL BLUE** erasable ink pen writings on **bond paper** reappeared when kept at -4°C.

Black Erasable Ink Samples:

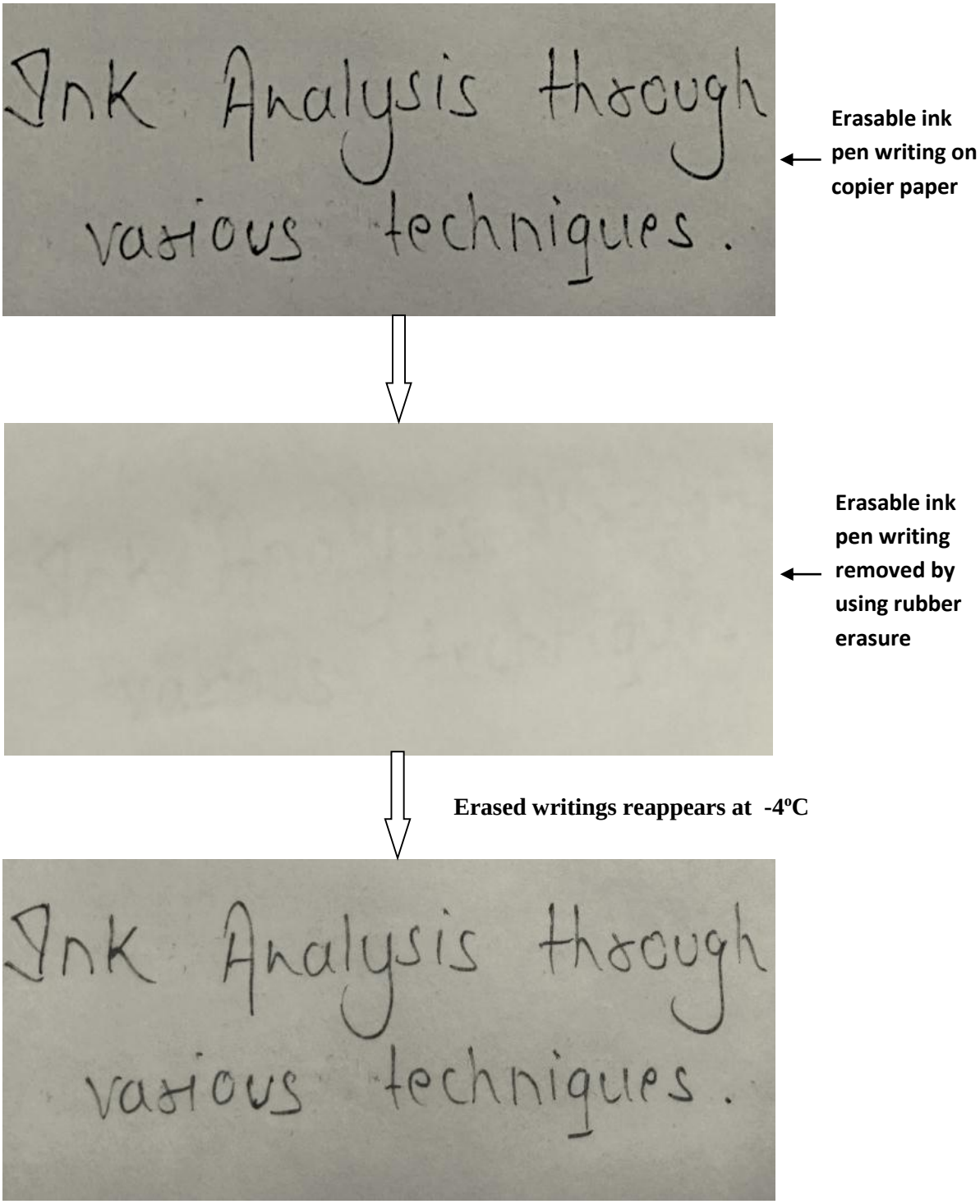


Figure 3.16: Sample of **Pilot BLACK** erasable ink pen writings on **bond paper** reappeared when kept at -4°C.

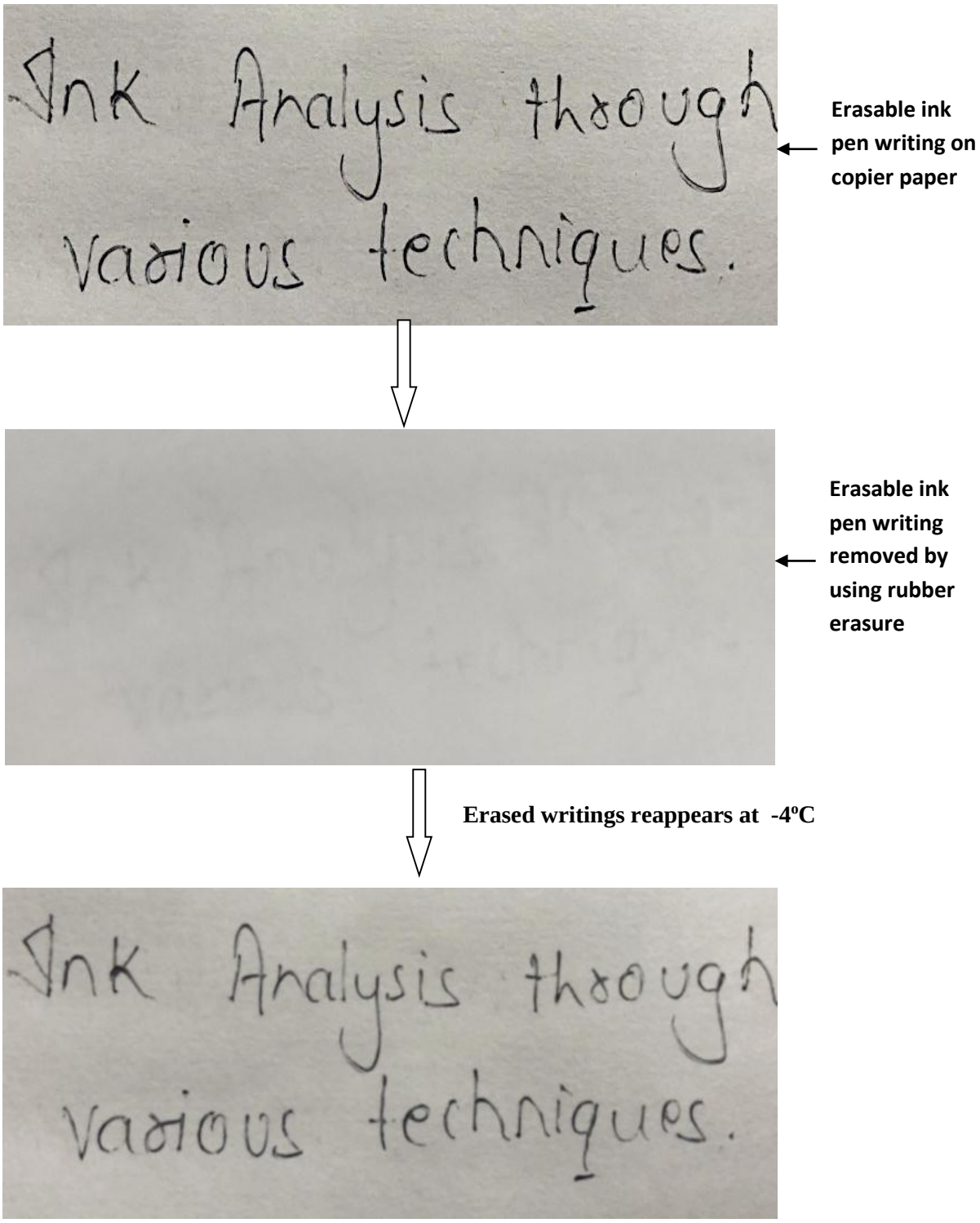


Figure 3.17: Sample of **Hamley Hamster BLACK** erasable ink pen writings on **bond paper** reappeared when kept at -4°C.

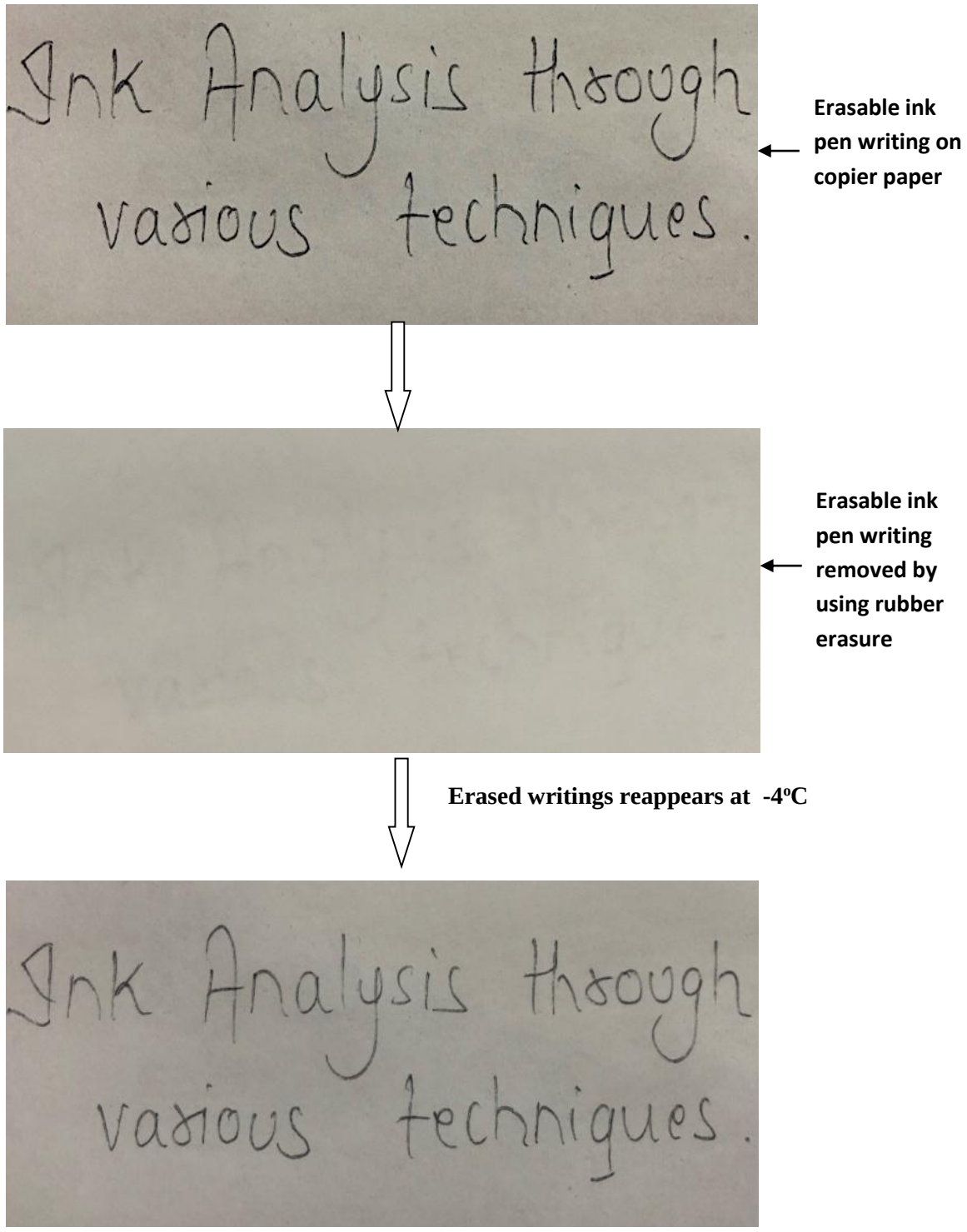


Figure 3.18: Sample of **UNIBALL BLACK** erasable ink pen writings on **bond paper** reappeared when kept at -4°C.

Red Erasable Ink Samples:

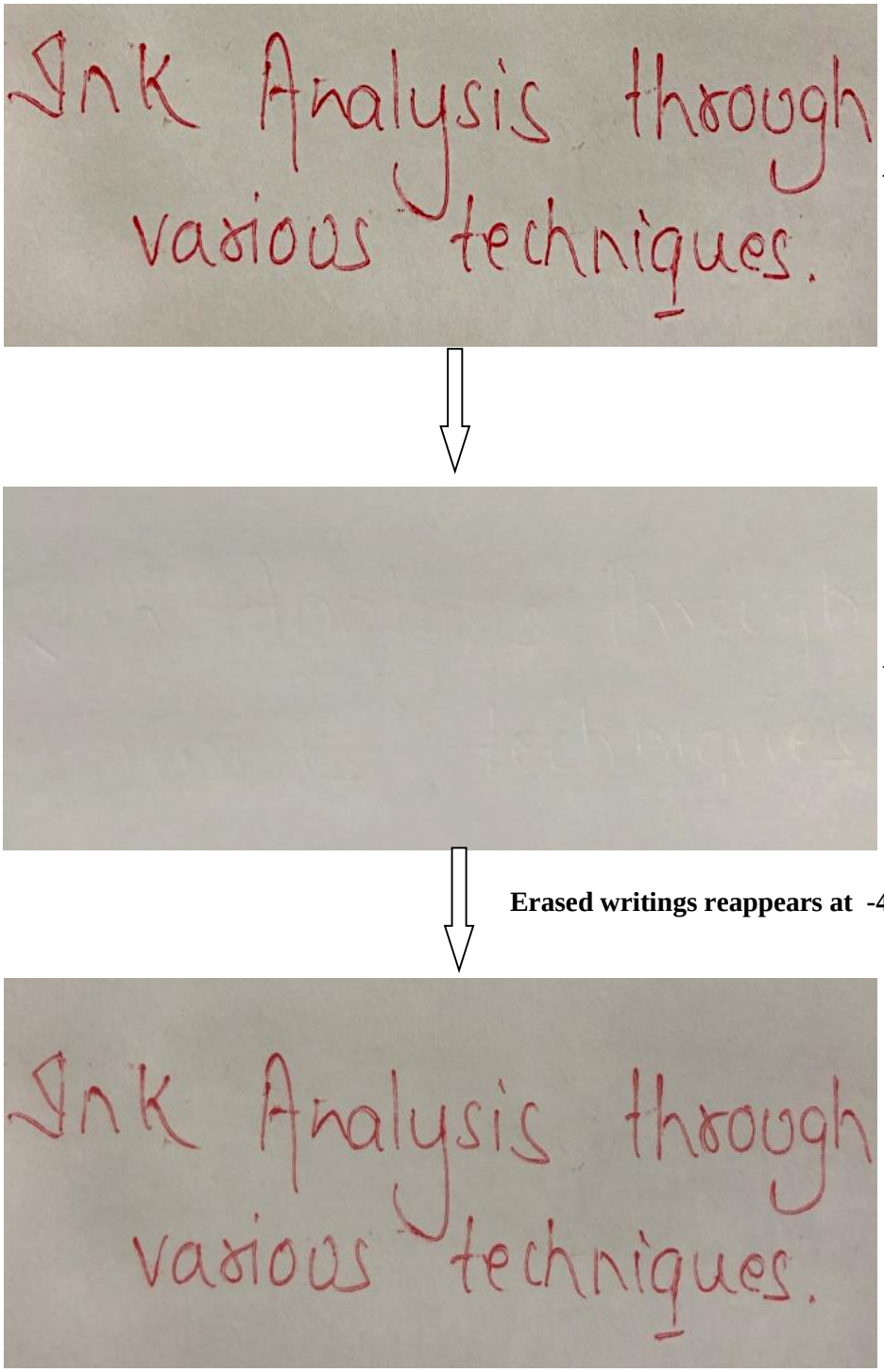
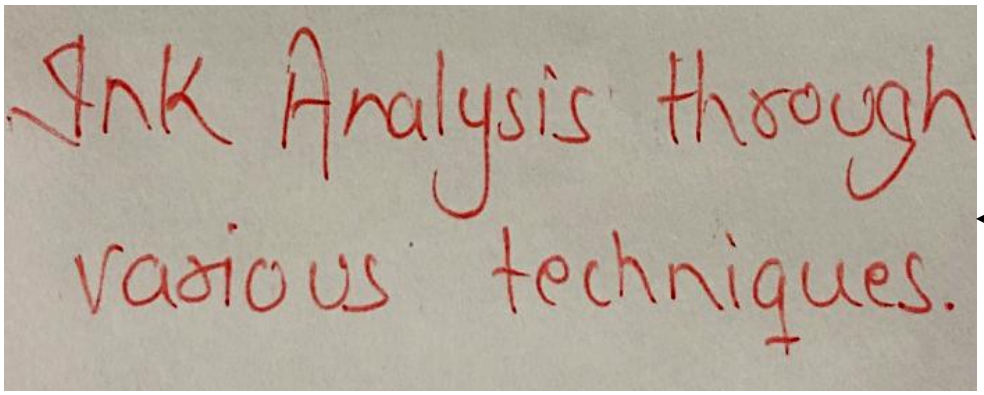
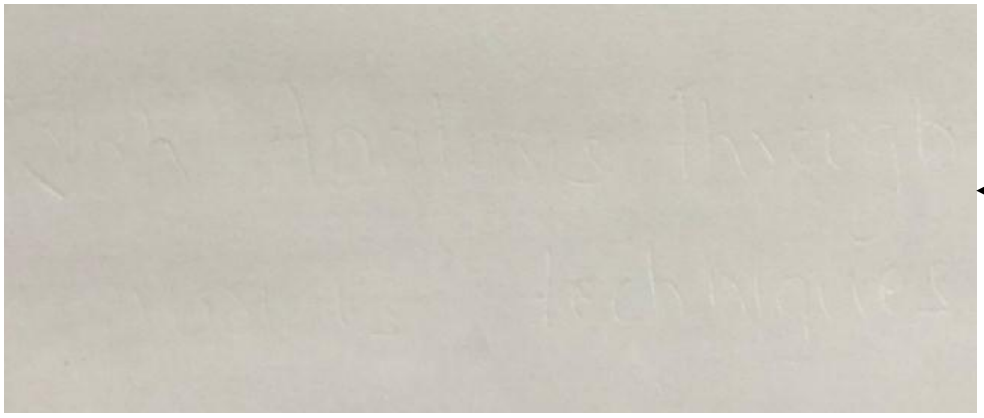


Figure 3.19: Sample of **Pilot RED** erasable ink pen writings on **bond paper** reappeared when kept at -4°C.



Erasable ink pen writing on copier paper



Erasable ink pen writing removed by using rubber erasure

Erased writings reappears at -4ºC

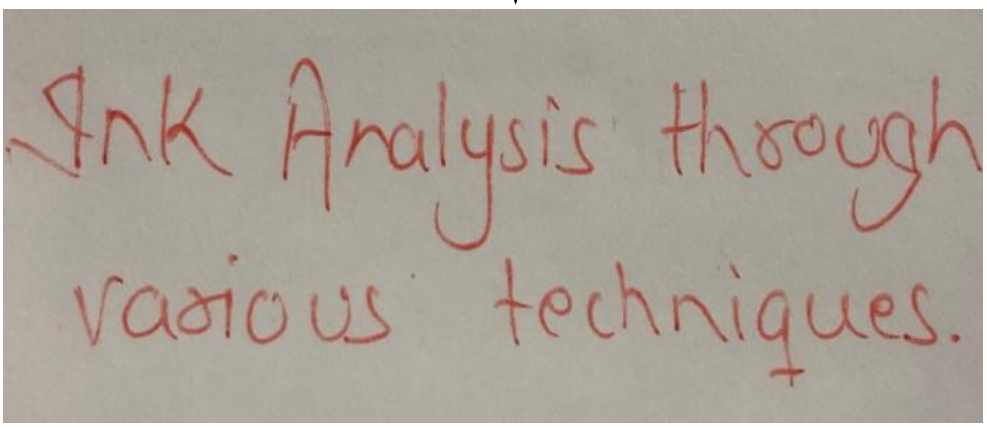


Figure 3.20: Sample of **Hamley Hamster RED** erasable ink pen writings on **bond paper** reappeared when kept at -4ºC.

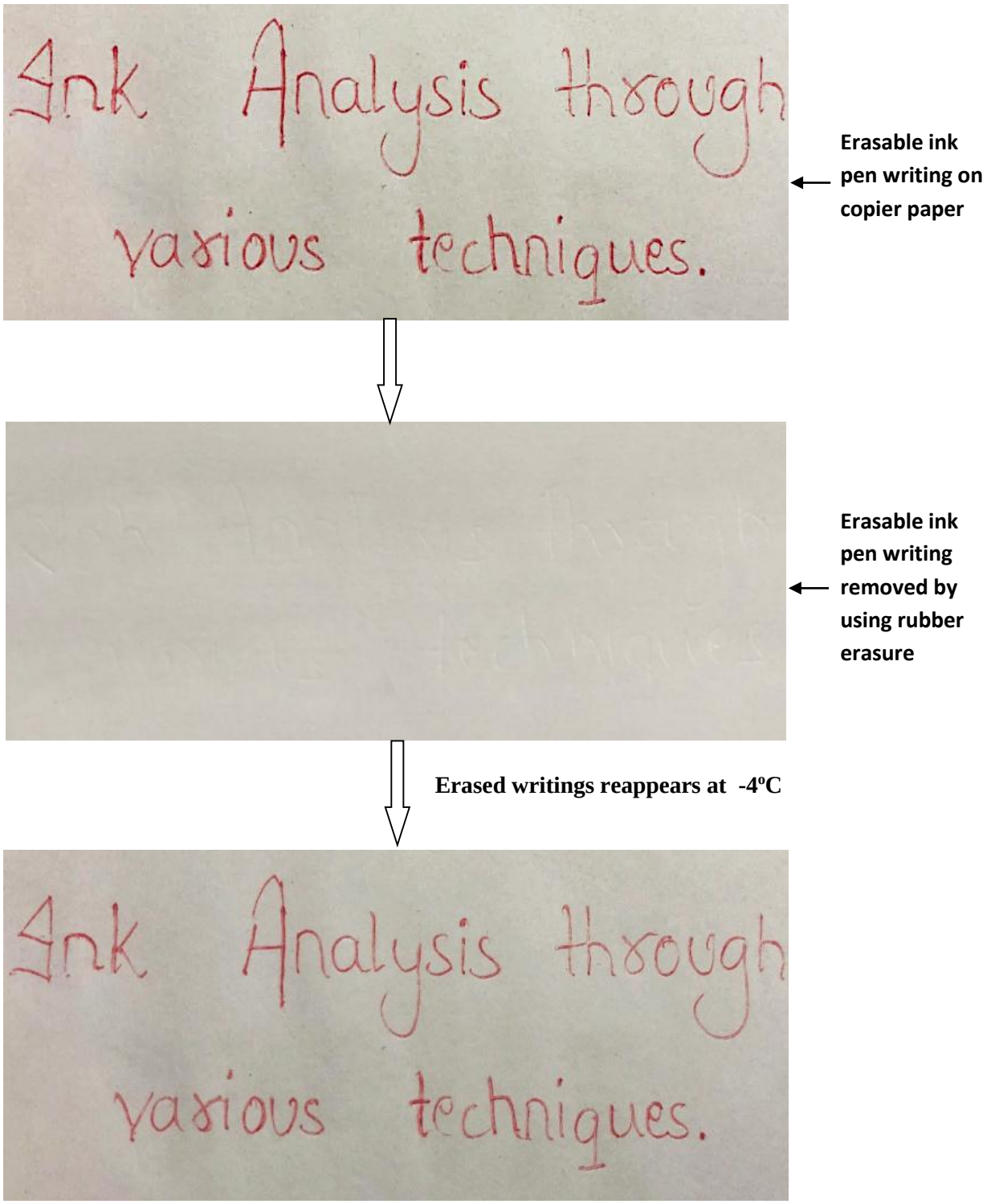


Figure 3.21: Sample of **UNIBALL RED** erasable ink pen writings on **bond paper** reappeared when kept at -4°C.

3.3.3 Results on Glossy Paper:

Glossy paper is a very high quality and smooth paper mostly used to print colourful sharp photographs. It is coated with a high-shine polymer which makes it smooth. More smudges and smears occur on glossy paper due to its smooth surface.

Glossy paper reacts differently as compared to copier paper and bond paper. In case of Pilot brand erasable ink pens when friction erasing method was used to remove ink lines from the glossy paper, it was observed that even after keeping it in a domestic refrigerator for sufficient time, the writings doesn't reappear. Only traces at the end of strokes reappeared. It was also observed that when ink lines were removed by using hair dryer and domestic iron then it gets reappeared within 20 minutes when kept under the refrigerated.

In case of Hamley Hamster and UNIBALL brand all the writings removed by all the three methods get reappeared when kept under the refrigerator for sufficient time.

Black and red ink gives a slightly smudged appearance when friction erasing method was used.

Figure 3.22: Few traces at the end of strokes reappeared when **Pilot BLUE** pen writings on the **glossy paper** is removed by using friction (rubber erasure)

Figure 3.23: Few traces at the end of strokes reappeared when **Pilot BLACK** pen writings on the **glossy paper** is removed by using friction (rubber erasure)

Figure 3.24: Few traces at the end of strokes reappeared when **Pilot RED** pen writings on the **glossy paper** is removed by using friction (rubber erasure)

Blue Erasable Ink Samples:

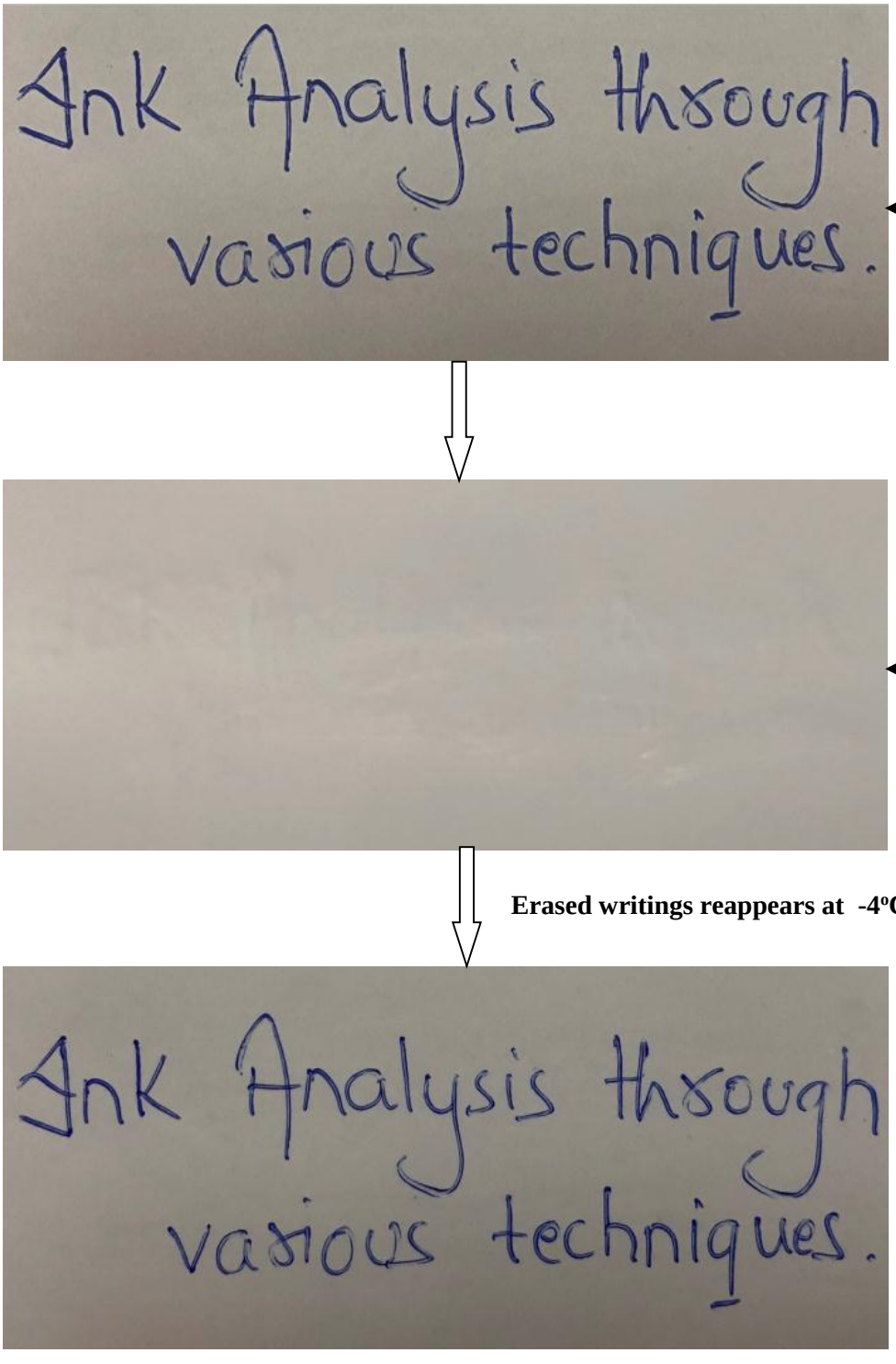


Figure 3.25: Sample of **Hamley Hamster BLUE** erasable ink pen writings on **glossy paper** reappeared when kept at -4°C.

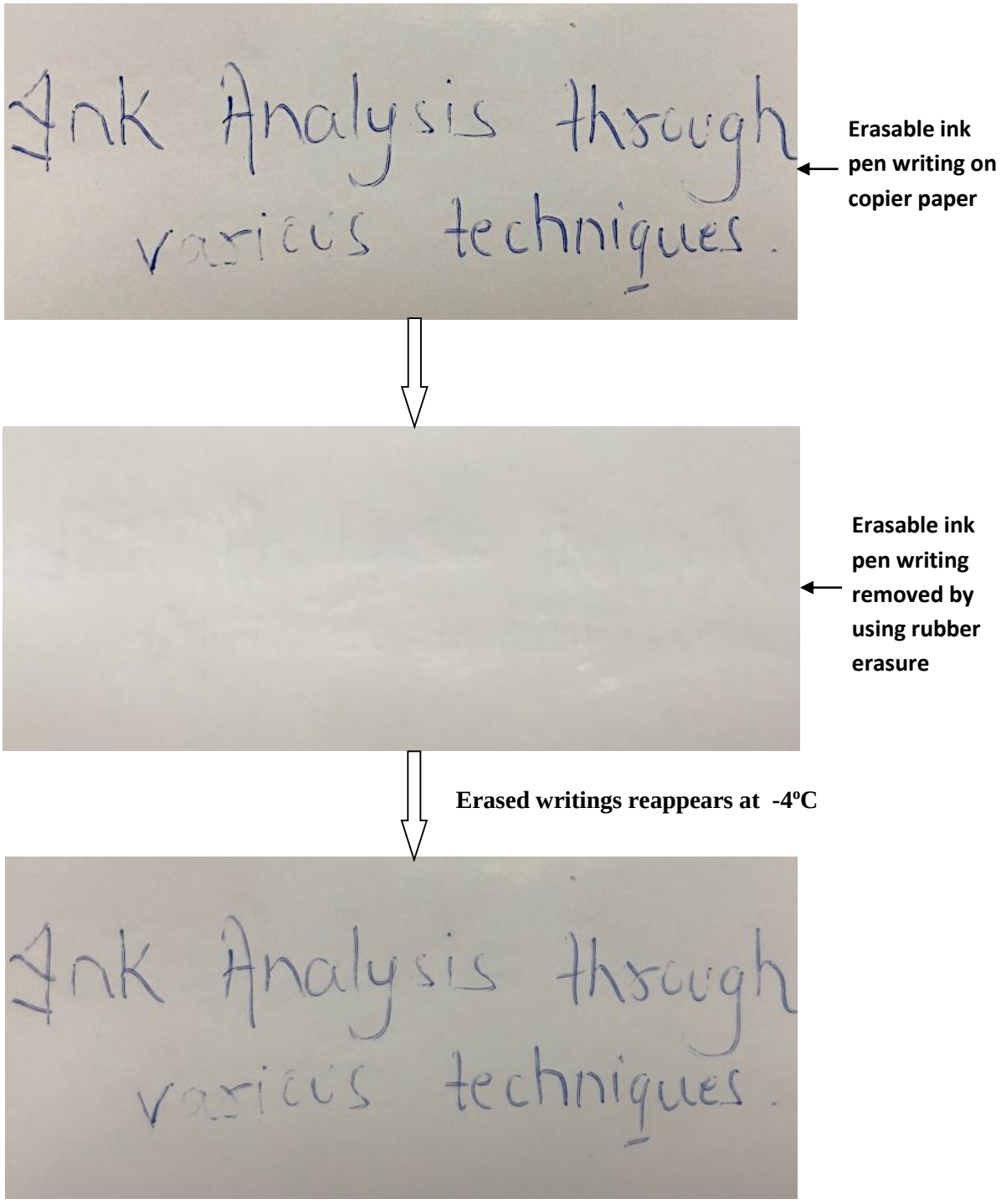


Figure 3.26: Sample of **UNIBALL BLUE** erasable ink pen writings on **glossy paper** reappeared when kept at -4°C.

Black Erasable Ink Samples:

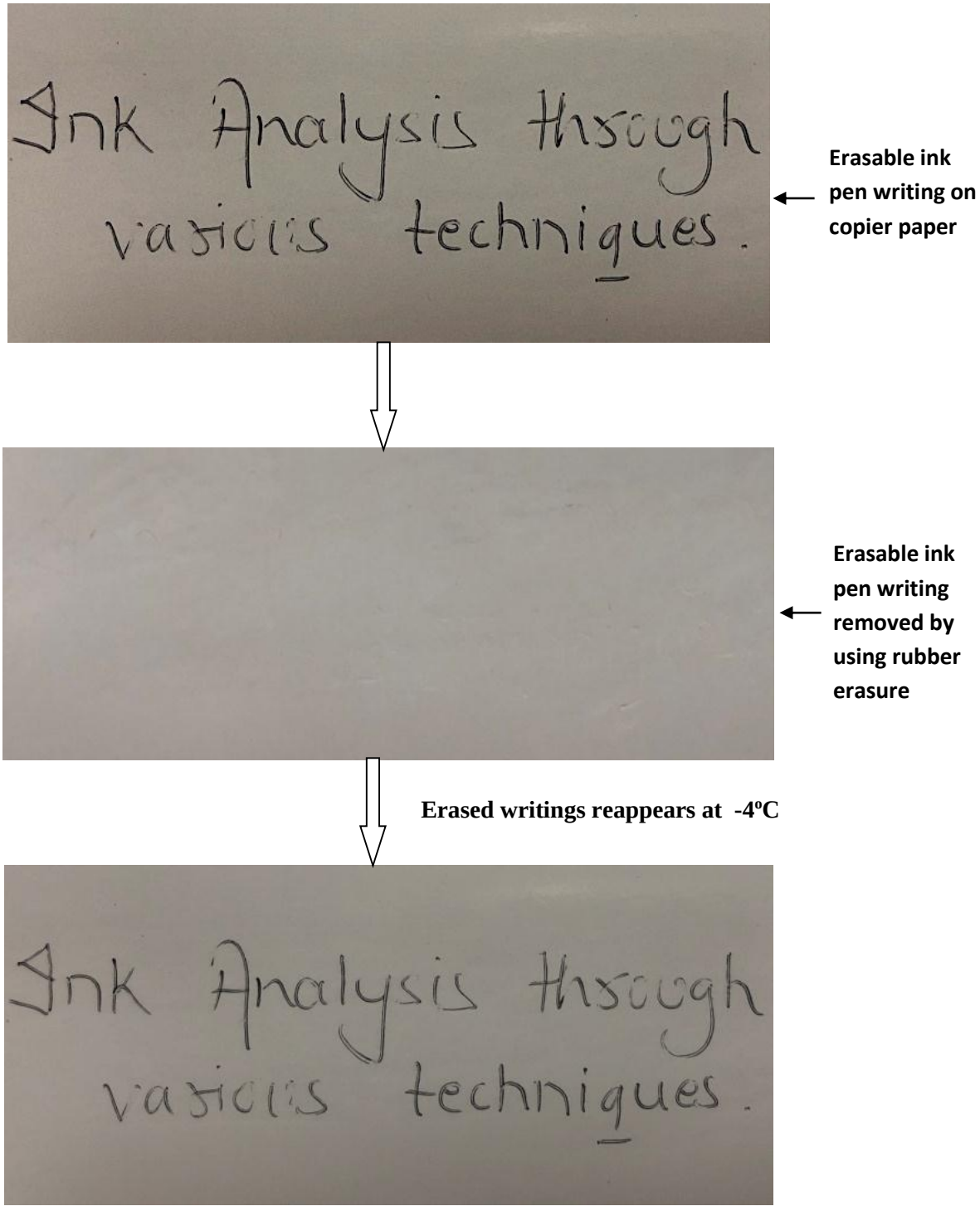


Figure 3.27: Sample of **Hamley Hamster BLACK** erasable ink pen writings on **glossy paper** reappeared when kept at -4°C.

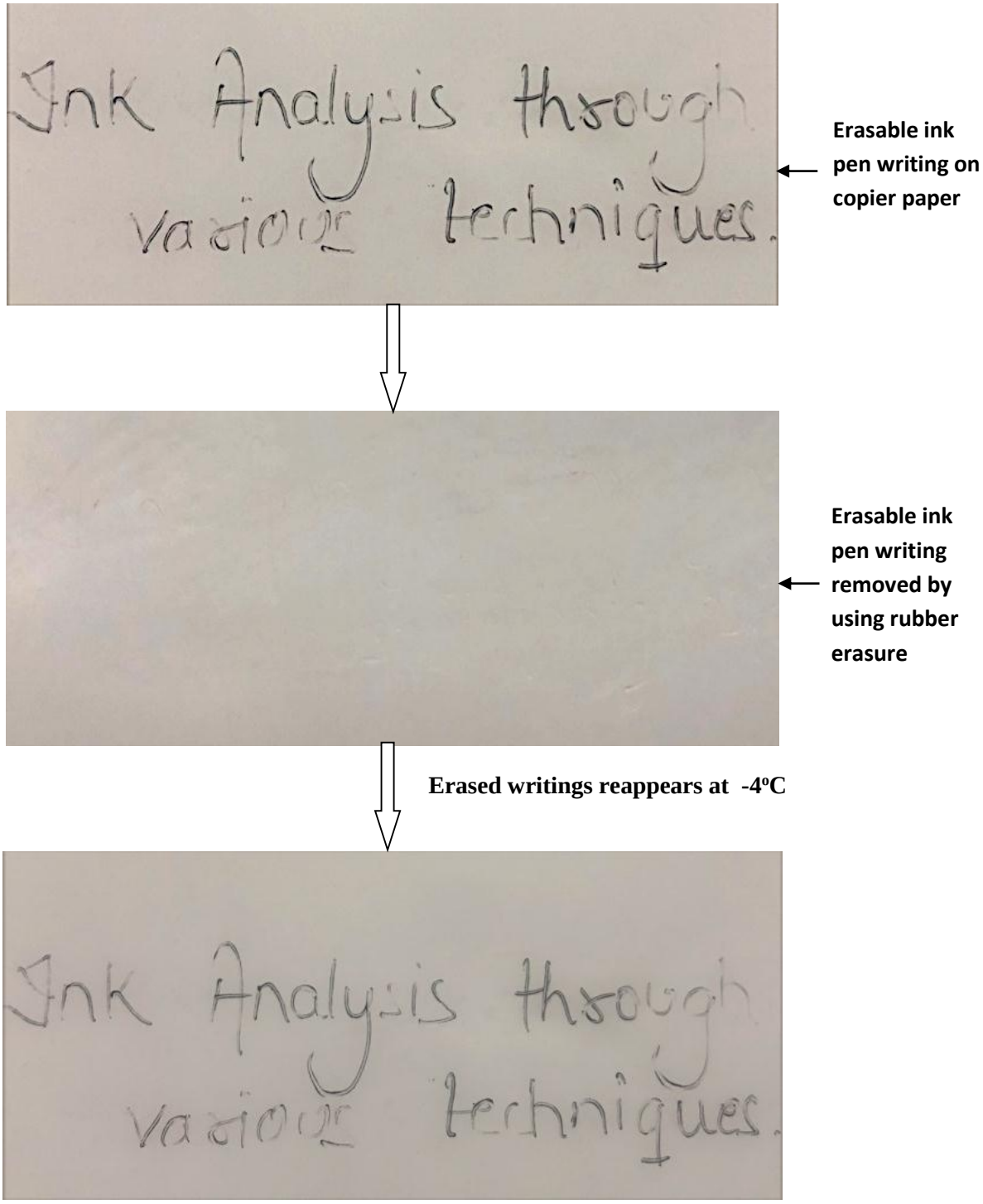


Figure 3.28: Sample of **UNIBALL BLACK** erasable ink pen writings on **glossy paper** reappeared when kept at -4°C.

Red Erasable Ink Samples:

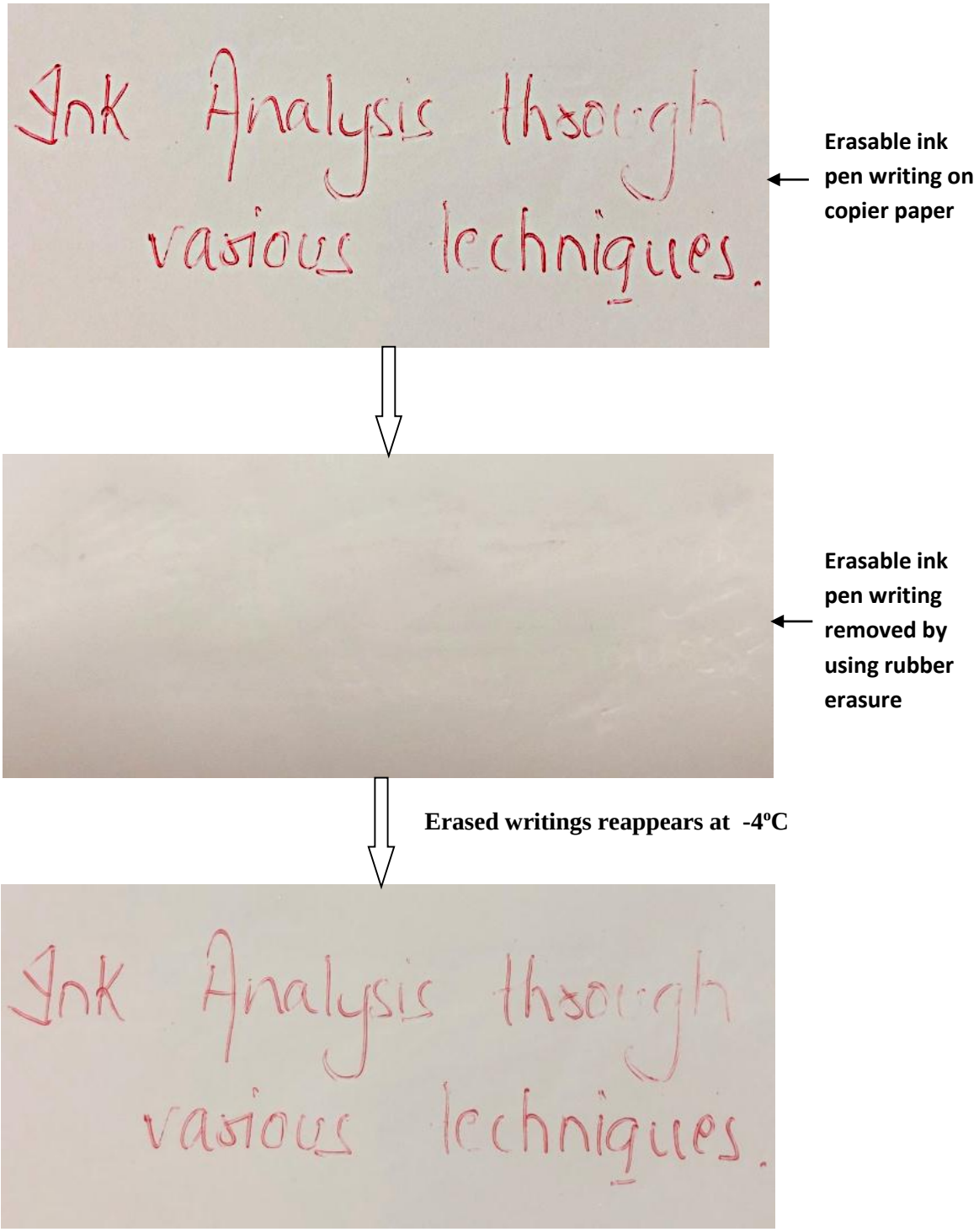


Figure 3.29: Sample of **Hamley Hamster RED** erasable ink pen writings on **glossy paper** reappeared when kept at -4ºC.

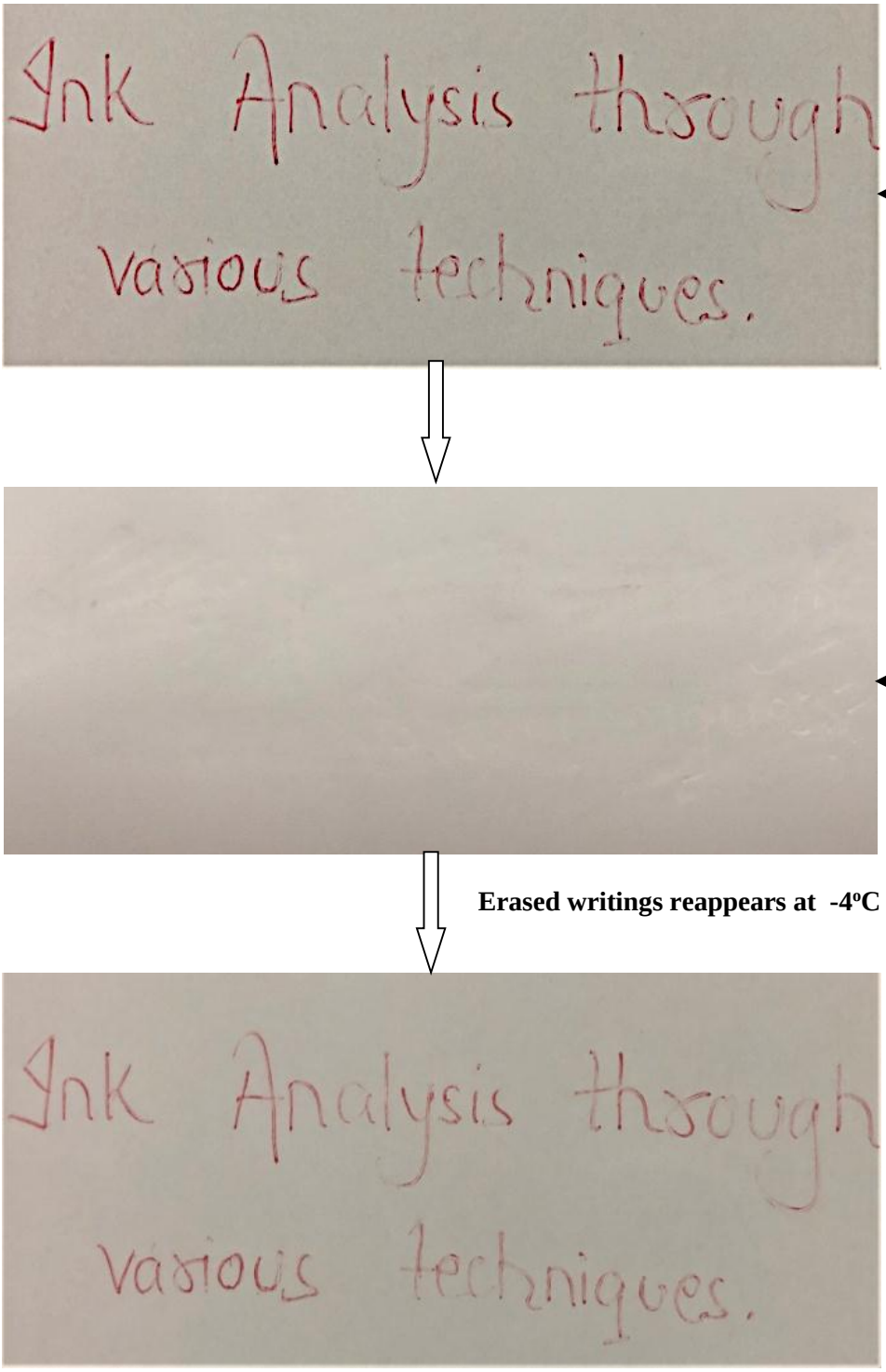


Figure 3.30: Sample of **UNIBALL RED** erasable ink pen writings on **glossy paper** reappeared when kept at -4°C.

3.3.4 Results of Disappearing Ink:

Disappearing ink works on the principle of acid-base reactivity. It react with the atmospheric carbon dioxide and disappear slowly. Temperature do not have any effect on these type of inks. Image shown below shows that unlike thermal erasable ink disappearing ink doesn't reappear when low temperature is provided to the writings. Results are same with all three types of paper.

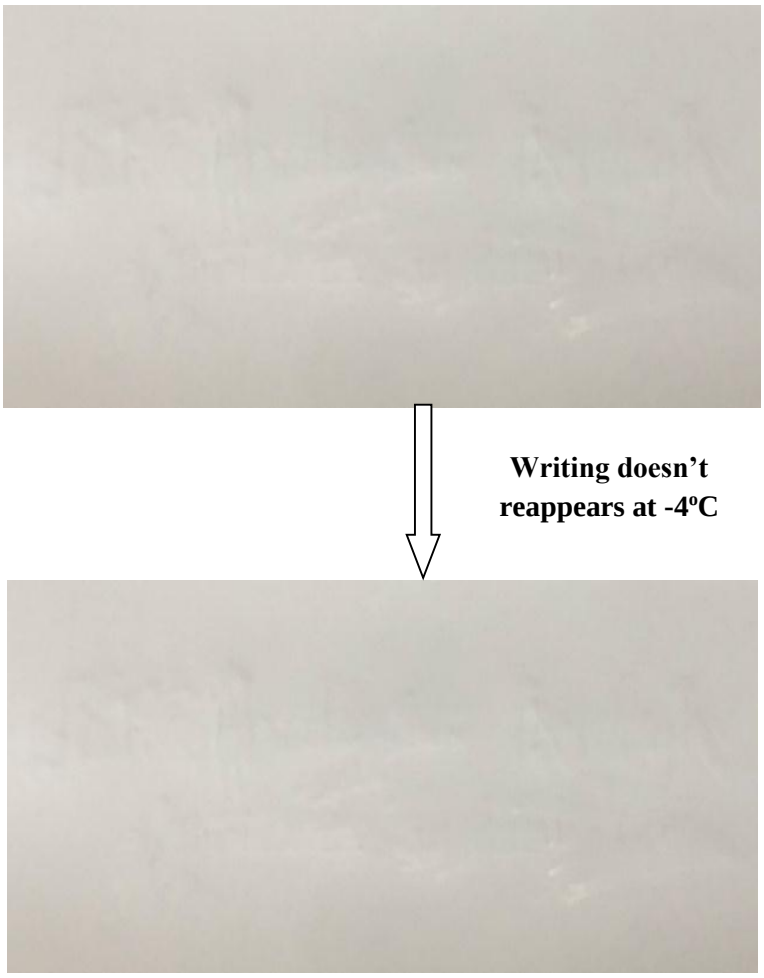


Figure 3.31: Sample of **Disappearing Ink** pen writings on **copier paper** which doesn't reappear even after keeping it at -4ºC for sufficient time.

3.4 Conclusion:

Easy availability and unique quality of thermal inks attracts criminal minds and therefore increases criminal activities. It is difficult to detect disappeared invisible ink writings by naked eyes. It was observed that among all three methods used, applying heat by iron is the fastest method to remove thermal ink writings.

It was also found that writings of Hamley hamster pens reappeared quickly (within 1min) when kept in a refrigerator. Pilot pen writings take longest time to reappear than the other two pen brands.

This happens because thermal ink consist of basic three components i.e. leuco dye, colour developer and a temperature regular which acts like an inhibitor. Leuco dye can switch between colour and colourless form depending upon the temperature. At high temperatures approximately above 60oC the temperature regular behave like an inhibitor and prevent the bonding of leuco dye and colour developer by itself bonding with colour developer which results in disappearing of the ink. Now if low temperature is provided approximately below 4oC, the inhibitor becomes inactive resulting in the bonding of leuco dye and the colour developer which results in reappearing of the ink colour.

Disappearing ink doesn’t have any effect of temperature and hence doesn’t reappear by refrigeration method.

It is very important to spread awareness and alerts the forensic society about the existence of these invisible ink pens and also describes an inexpensive, easy and non-destructive method to decipher such writings. Some of the important features and properties of erasable ink are also elaborated in this chapter.

Restoration of disappeared writing by using an easily available domestic refrigerator provides a new avenue to detect these temperature dependent ink writings. Refrigeration method doesn't work on glossy paper when ink-lines are removed by pen erasure. In all other cases restoration by putting the samples in a refrigerator is possible.

CHAPTER – 4

TO RESTORE THE INVISIBLE WRITINGS THROUGH VARIOUS TECHNIQUES

4.1 Introduction

Ink is a solution that contains dyes or pigments that produce colour when applied to a surface to produce an image, text, drawing and design with the help of pen or brush.

Invisible inks are also called as magic inks or sometimes called as sympathetic inks. It is a solution used for drawing or writing, which can be erased or become invisible after few minutes (145). A new technique of committing forgeries using these magic pens has increased the number of white collar crimes dramatically. So it becomes important to formulate a practical, easy and a cost effective method to decipher such writings. Invisible inks are easily available in the local market which raises a great deal of concern (148). The main two varieties of invisible inks are disappearing ink and thermal ink.

Erasable ink is used as a tool to forge various types of documents. It can be removed easily by the rubber incorporated at the tip of the pen. For an erasable ink, the writing strokes of an erasable ink are manually manipulated with the help of the incorporated erasure. It is available in different colours likes red, blue, green and black. Erasable ink is a type of ink that depends on the temperature of the ink solvent generated during erasure. This ink starts fading when the temperature increases either manually by friction or by other direct sources.

These temperature dependent inks are becoming popular among criminals and are used for committing various types of crimes. These Paper Mate manufactured erasable ink pens are sold under the name of "Replay" in UK. But now the brand of these erasable pens in UK had changed from Replay to "Erase Max". Pilot is manufacturing a large collection of erasable ink pens under the name "Frixion" erasable roller pen.

Solvent system mostly used in the preparation of thermal inks is leuco dye developer solvent system. It is encapsulated in a polymer shield. Colour change from coloured to colourless or vice-versa take place due to the interaction of three components i.e. leuco dye which is a colour former, developer and a solvent. Spirolactone molecule can be used as a colour former. CVL (Crystal Violet Lactone) can be used as colour former, it is colourless in grounded form. Phenols are commonly used as developers in this ink. Most commonly used solvents in the preparation of disappearing ink are alcohol, amides, esters and acids having long chain aliphatic character (150).

Disappearing ink works on the basic principle of acid-base chemistry. It is made from a mixture of chemicals and it remains visible to the naked eye only for a short period of time depending upon the writing surface. Most common pH indicator to make these inks is Thymolphthalein ($C_{28}H_{30}O_4$) is used for the preparation of blue coloured ink at the pH 9.3-10.5 and Phenolphthalein $C_{20}H_{16}O_4$ (colourless to red at pH 8.2 - 9.8). Disappearing ink mainly consist of following components, a pH indicator like phenolphthalein or thymolphthalein, a base like sodium hydroxide (NaOH) solution, ethyl alcohol and distilled water at pH-11. Increasing the temperature of sodium hydroxide leads to increased stability of the ink (151).

The water (H_2O) present in the solution of ink reacts with atmospheric carbon dioxide (CO_2) I order to form carbonic acid. Sodium hydroxide (NaOH) then reacts with carbonic acid to form sodium carbonate which is a neutralization reaction. Due to this neutralization reaction, pH changes from basic to acidic and makes the indicator colourless, hence ink gets disappeared (143):

Carbon dioxide (CO_2) present in the atmosphere reacts with water (H_2O) to form carbonic acid:

$$\mathbf{CO_2 + H_2O \rightarrow H_2CO_3}$$

In a neutralization reaction, carbonic acid formed reacts with sodium hydroxide (NaOH). Sodium hydroxide reacted with carbon dioxide (CO_2) in the air to form sodium carbonate, whose pH is less basic than sodium hydroxide.

$$\mathbf{2Na(OH) + H_2CO_3 \rightarrow Na_2CO_3 + 2H_2O}$$

$$\mathbf{2\ NaOH + CO_2 + H_2O \rightarrow Na_2CO_3 + 2\ H_2O}$$

Sodium carbonate is responsible for changing the colour of the indicator from blue to colourless.

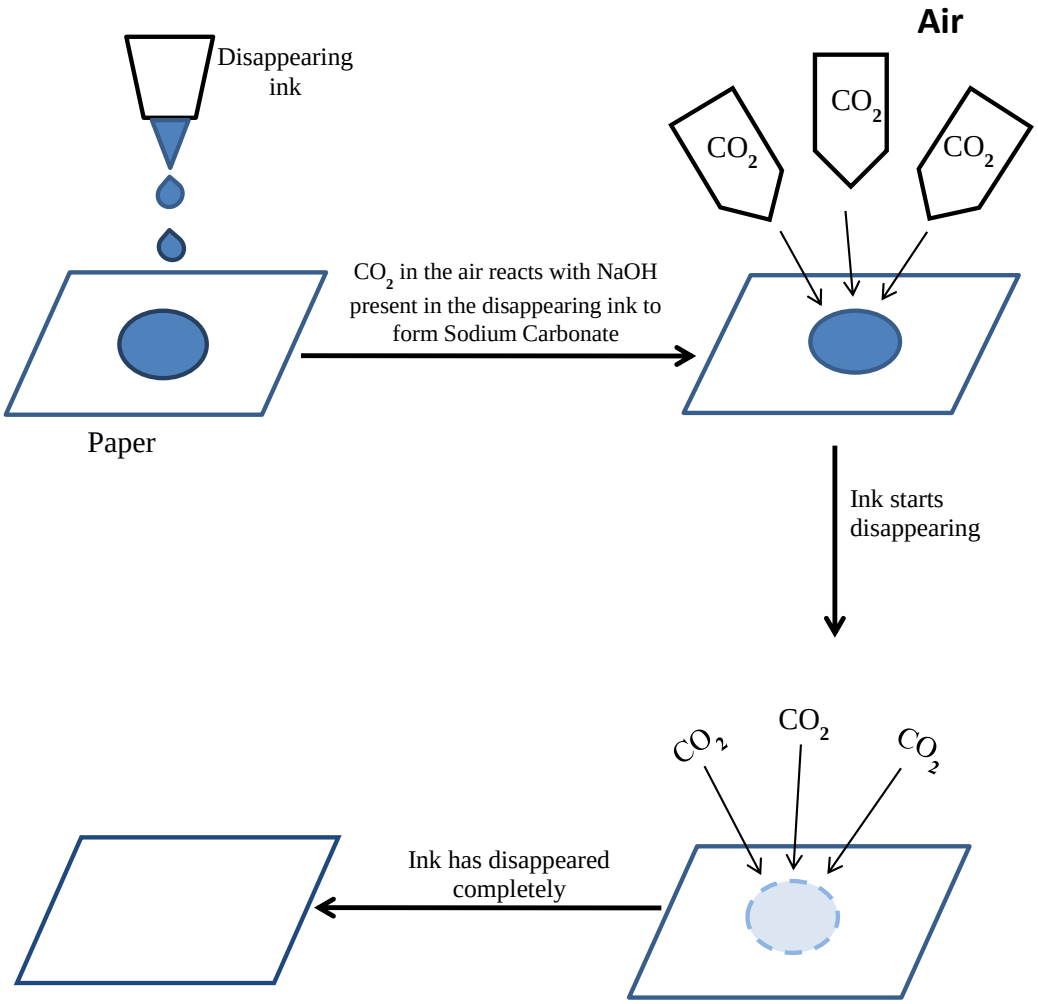


Figure 4.1: Mechanism of disappearing ink

Disappearing ink is very important in the textile industries as it is used as a tool in dressmaking and also as a teaching material and to draw the design on the fabric or to mark something on the fabrics as the lines or marks will disappear after sometime. These inks are also used as paint. For example, it is difficult to determine which parts of an existing coat of white paint are not covered by the new layer similar colour paint especially under poor lighting; disappearing ink can solve the problem (152)**.** It is also utilized in the marking system of various fields that needs proper placement of steps like sports training classes, dance classes etc**.** These pens are also used by the teachers

at school or college level for preparing papers where questions are visible but answers remain invisible until a colouring assistant is used (153). Now a day's these inks are used for committing various forgeries mainly related to banks, wills, property documents, etc.

4.2 Methodology:

4.2.1 Material Used:

1. Blue disappearing ink pen (Vikson International brand)
2. Blue, Black & Red erasable ink pen of 3 different brands: Pilot, Hamley Hamster and Uniball
3. Three variety of papers: White Copier paper (70gsm), Bond paper (90gsm) and Glossy paper (180gsm)
4. Mobile flash light (iPhone 12Pro)
5. Photoshop7 software
6. U.V. Cabinet
7. Iodine crystals
8. Sodium hydroxide
9. Video Spectral Comparator -8000

4.2.2 Preparation of Samples:

There are total 1500 samples collected including all the different methods used for decipherment of invisible ink in this chapter.

Samples were prepared by using erasable ink pen & disappearing ink pen on three different variety of papers i.e. copier paper, bond paper & glossy paper.

Writings of erasable pen are removed by using pen erasure fitted at the tip of each pen.

The test samples were examined with different techniques like U.V. Cabinet, oblique light, Chemical examination methods, VSC etc.

4.3 Techniques used for examination:

4.3.1 Adobe Photoshop Software:

Adobe Photoshop is an editing software used in graphic designing and various other editing purposes. It offers a wide range of editing options like illustration, image enhancement, artwork and editing. Adobe Photoshop creates an immersive experience by simulation and creating alternative views of space. It is undoubtedly the most widely used software for editing and graphic designing. Adobe Photoshop is used in creating website layouts which are later programmed by developers.

We utilised Photoshop software to enhance the images of the samples in order to decipher the erased writings.

4.3.2 U.V. Cabinet:

Figure 4.2: U.V. Cabinet

This is a cabinet specially designed for chromatographic analysis by ultra violet (U.V.) fluorescence for viewing of fluorescent samples without interference from ambient light. It is a simple, fast and suitable technique for fluorescence analysis under lab conditions. Chromatogram viewing U.V. cabinet combines both waves long as well as short UV fluorescence and also white light. The self-contained unit is specially designed for easy analysis, viewing and making of accurate chromatograms and also for studying general fluorescence. One can view

chromatograms at long U.V. range of 365nm or short U.V. range of 254nm. It can also be viewed with white light in a smaller table top which is capable of accommodating three methods for finding and recognizing parts.

4.3.3 Iodine Fuming Method:

Figure 4.3: Crystals of Iodine

Iodine fuming method was used to decipher the faded writing on the different type of documents. For giving fumes to the samples, 1g Iodine crystals are placed in a closed fuming cabinet. The object bearing the erased writings is suspended from the roof of the cabinet. The erased writings was deciphered with the fumes of iodine within 2 to 5 minutes. Glossy paper takes more time as compared to copier paper and bond paper because of its thickness. Photograph of the deciphered writing must be taken immediately with the help of the camera.

Ammonia fumes were also given to the sample but it doesn't give desired result.

4.3.4 Sodium Hydroxide Method:

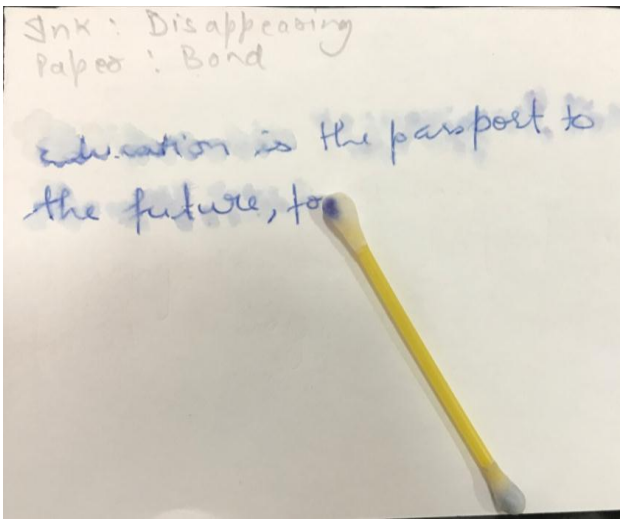


Figure 4.4: Decipherment using sodium hydroxide

5% NaOH or KOH solution were applied over the faded handwriting written on the different kind of papers with the help of cotton bud. Photograph of the deciphered writing must be taken immediately as it will be visible for a short time only. Ammonia was also applied over the samples to decipher the disappeared writing but it gives the negative test.

4.3.5 Video Spectral Comparator (VSC)

Video Spectral Comparator (Foster and Freeman) is the most widely used instrument available for the examination of suspicious documents. This instrument supports the non-destructive method for the examination of the questioned documents so that the documents remain intact. Video Spectral Comparator is an imaging device which allows differentiating between two inks, visualizing hidden security features, and helping to reveal alteration on the documents. This instrument is used to check the authenticity of various important documents like revenue stamps, wills, property documents, questioned signature or handwriting, banknotes, travel documents like driving license and other important documents. This system has also proven useful for faded or obliterated writing.

VSC works on the basic principle of light. It consist of various filters and light sources of U.V. light, visible light and infrared light which can be used for the examination of questioned documents.

VSC was the best way to decipher the faded writing on the different types of documents as its give the best result without affecting the paper samples.

4.4 Observation and Results:

After the examination of the ink sample on different types of the following result were obtained which are as follows: -

4.4.1 Decipherment using Adobe Photoshop software:

Total 150 samples were collected, 50 for each type of paper.

- Writings of erasable pen are removed by using pen erasure fitted at the tip of each pen.
- Samples were analysed in a dark room by using mobile phone flash light at different angles (below 45^{o}) and another mobile phone was used to click pictures of the same.
- Images of the sample are enhanced or analysed by using Photoshop software in order to decipher the erased writings.

It was observed that all the writings on different variety of paper can be easily decipher by this method.

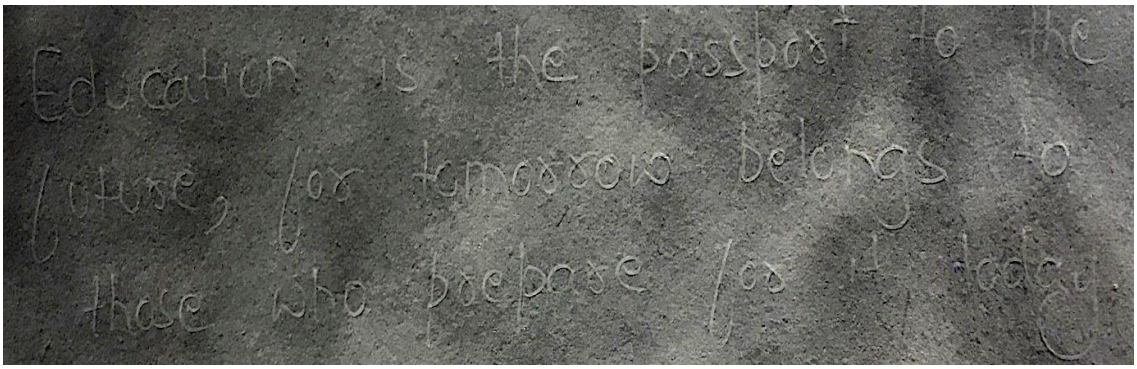


Figure 4.5: Reappeared writings on copier paper by Adobe Photoshop Software method

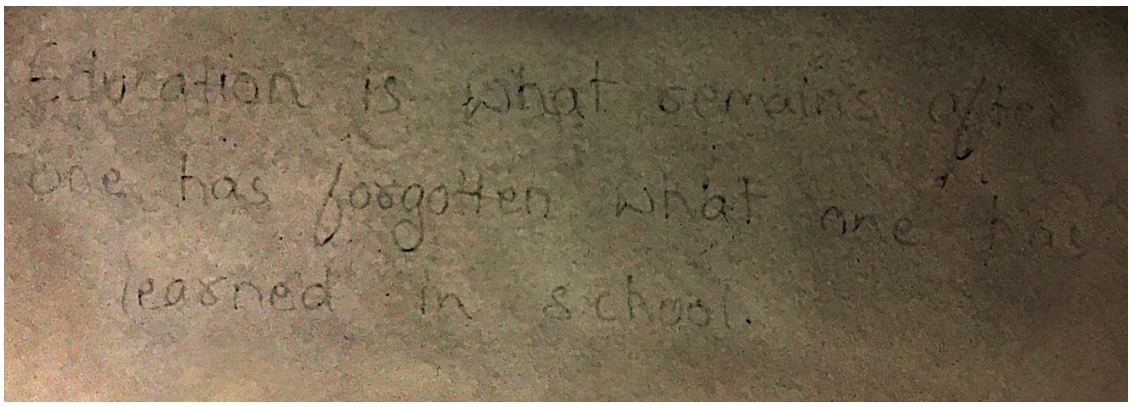


Figure 4.6: Reappeared writings on bond paper by Adobe Photoshop Software method

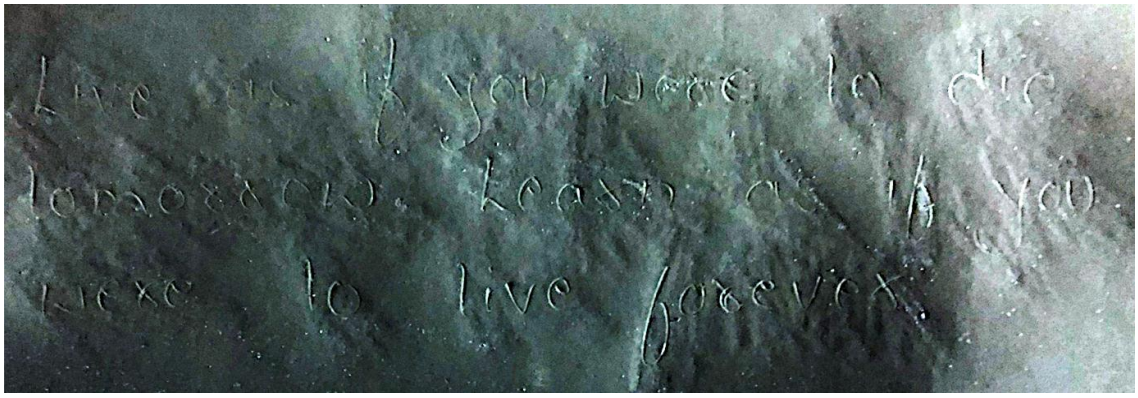


Figure 4.7: Reappeared writings on glossy paper by Adobe Photoshop Software method

4.4.2 Decipherment using U.V. Cabinet:

Total 300 samples were collected and examined, 150 sample for erasable ink (50 for each paper type) and 150 samples for disappearing ink (50 for each paper type).

- Samples were prepared by using erasable pen & disappearing ink pen on three different variety of papers i.e. copier paper, bond paper & glossy paper.
- Samples were analysed by keeping each sample in a U.V. Cabinet and analyzing each at short U.V. range (254nm) & long U.V. range (365nm).
- Photograph was taken by using a mobile phone.

Table 4.1: Results of examination of invisible writing by using U.V. Cabinet.

S.No.	Type of Ink	Type of paper	Examination Method	U.V. range (Long & short)	Result
1	Erasable	Copier	U.V. Cabinet	Both	Visible
2	Erasable	Bond	U.V. Cabinet	Both	Visible
3	Erasable	Glossy	U.V. Cabinet	Both	Visible
4	Disappearing	Copier	U.V. Cabinet	Long	Visible
5	Disappearing	Bond	U.V. Cabinet	Long	Visible
6	Disappearing	Glossy	U.V. Cabinet	Long	Visible

It was observed that the disappearing ink writings become visible at long U.V. (365nm) on all varieties of papers. The writings of erasable ink pen were visible at both long and short U.V. Light on all varieties of papers.

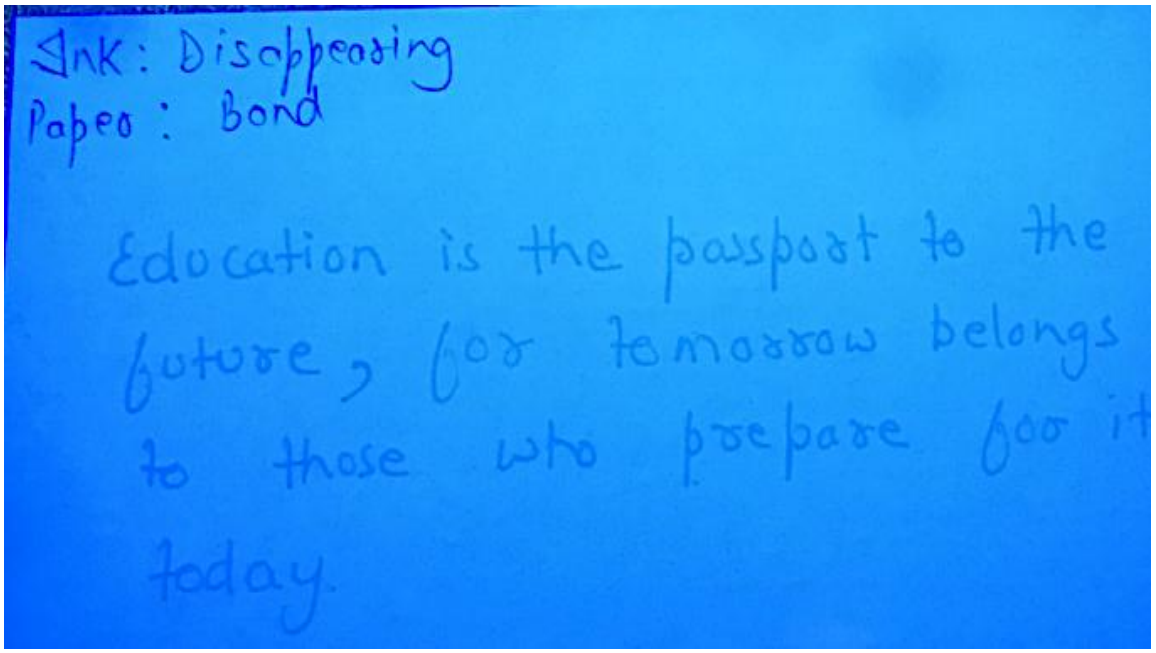


Figure 4.8: Reappeared writing of disappearing ink on bond paper by U.V. Cabinet.

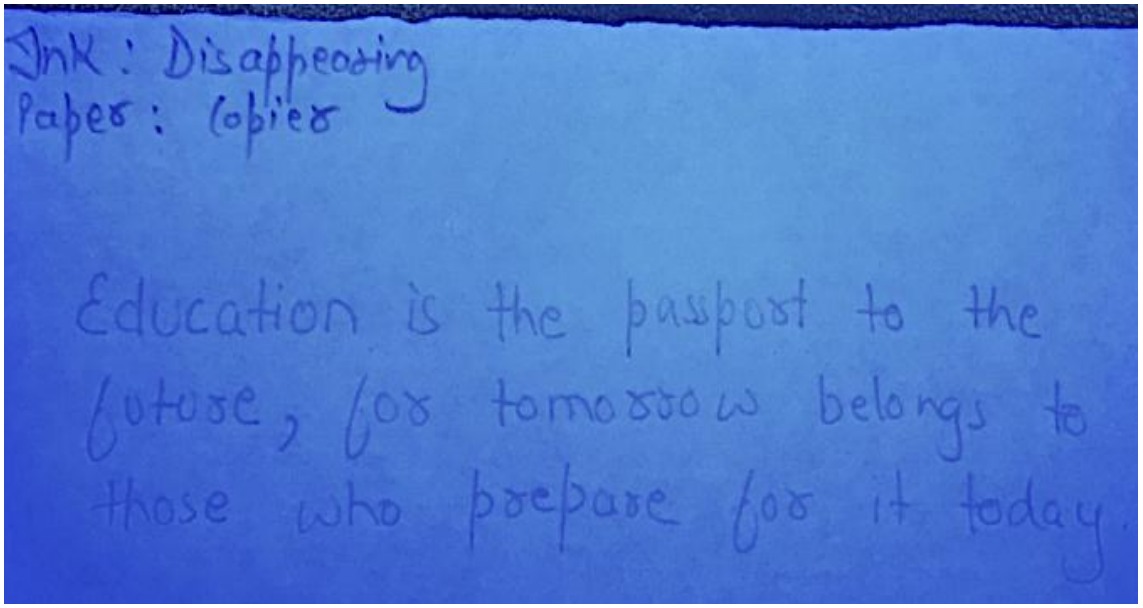


Figure 4.9: Reappeared writing of disappearing ink on copier paper by U.V. Cabinet.

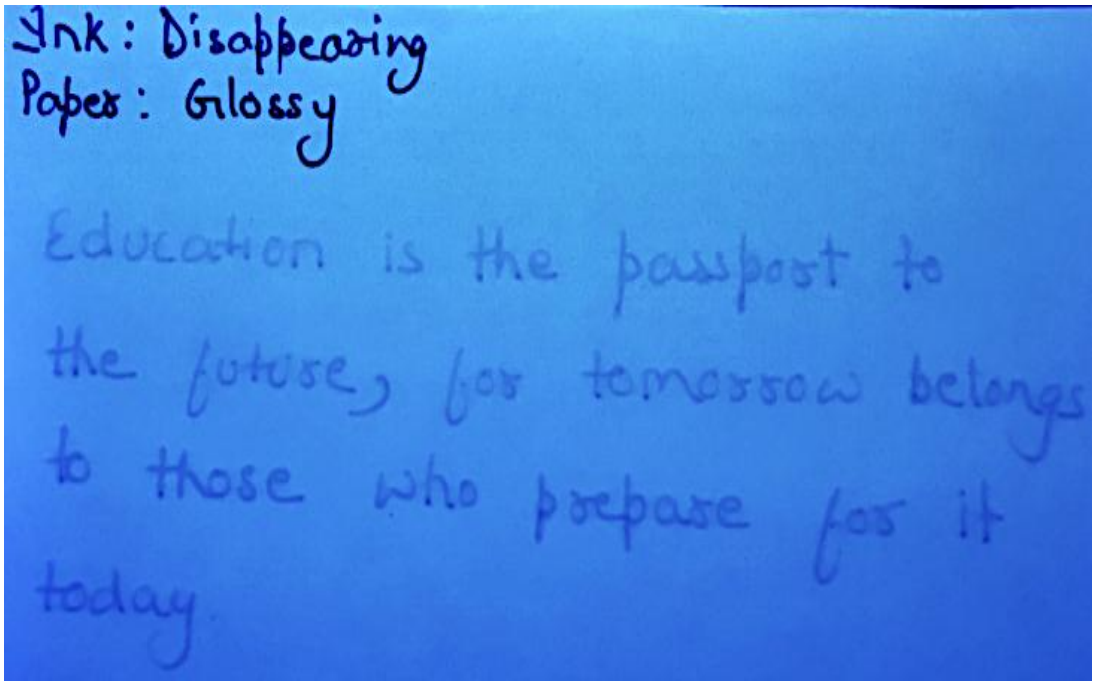


Figure 4.10: Reappeared writing of disappearing ink on glossy paper by U.V. Cabinet.

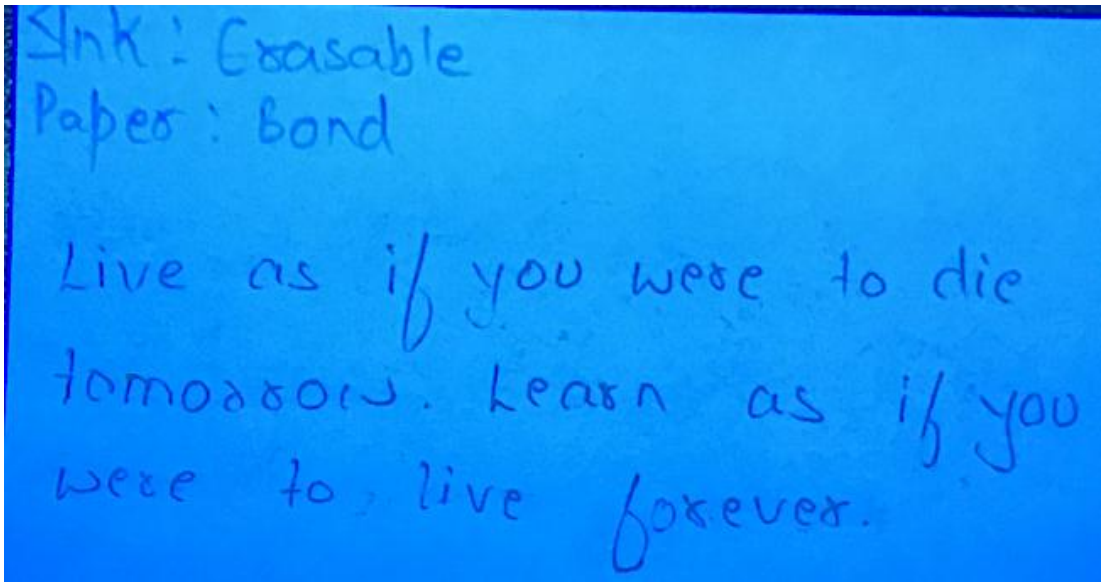


Figure 4.11: Reappeared writing of erasable ink on bond paper by U.V. Cabinet.

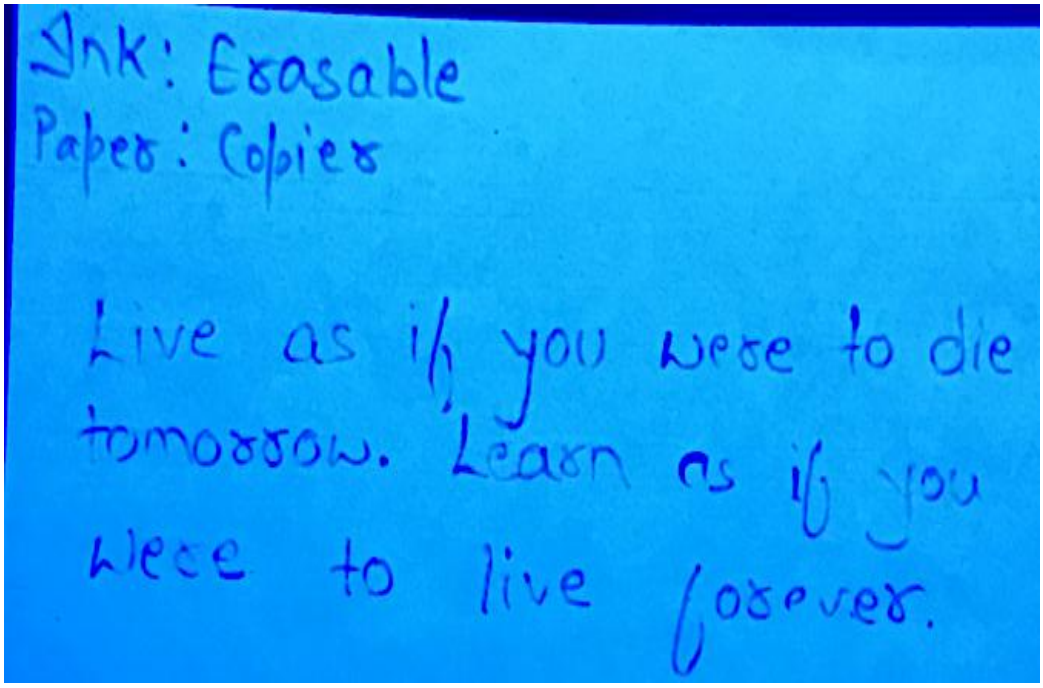


Figure 4.12: Reappeared writing of erasable ink on copier paper by U.V. Cabinet.

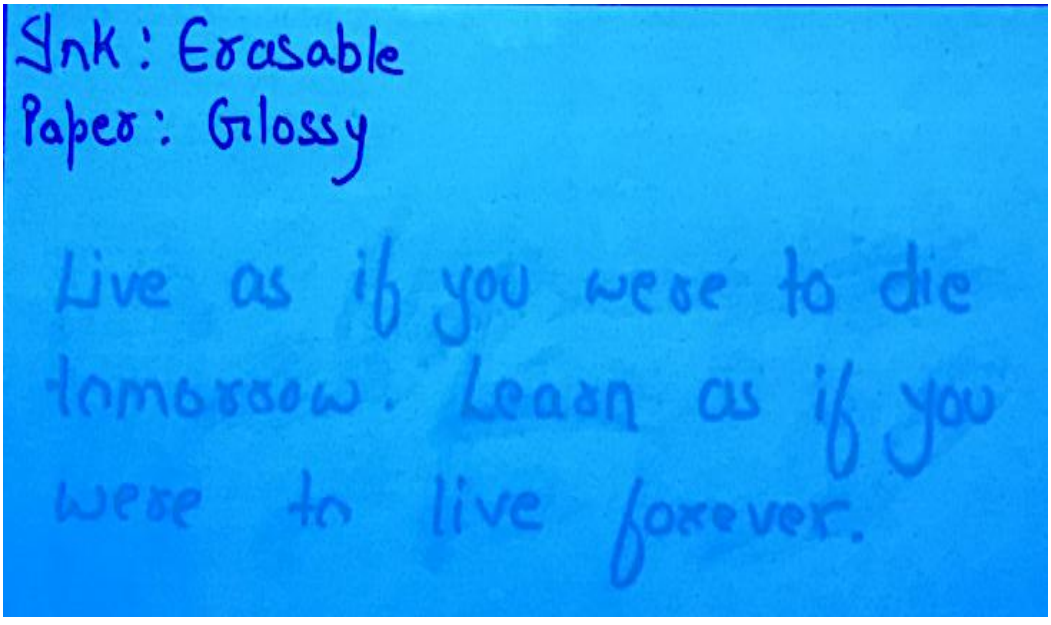


Figure 4.13: Reappeared writing of erasable ink on glossy paper by U.V. Cabinet.

4.4.3 Decipherment using Iodine Fuming method:

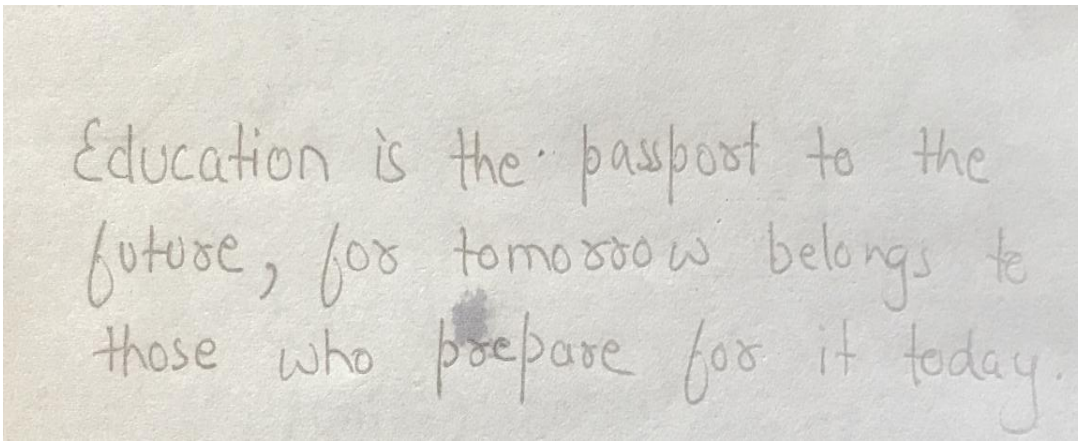
Total 300 samples were collected and examined, 150 sample for erasable ink (50 for each paper type) and 150 samples for disappearing ink (50 for each paper type).

The faded writing was visible when treated with the iodine crystals fumes. The paper samples were hanged over the iodine crystals which produced fumes inside the closed chamber resulted in the decipherment of disappearing ink. The mechanism behind visualization of the faded writing is that when the samples were written with the disappearing ink or erasable ink, it disturb the surface fibers of the paper so when the iodine fuming is done, the iodine sticks preferentially to the altered areas of the paper (20) and developed as brown writing. The camera was ready to capture the image as the writing was visible only for some time.

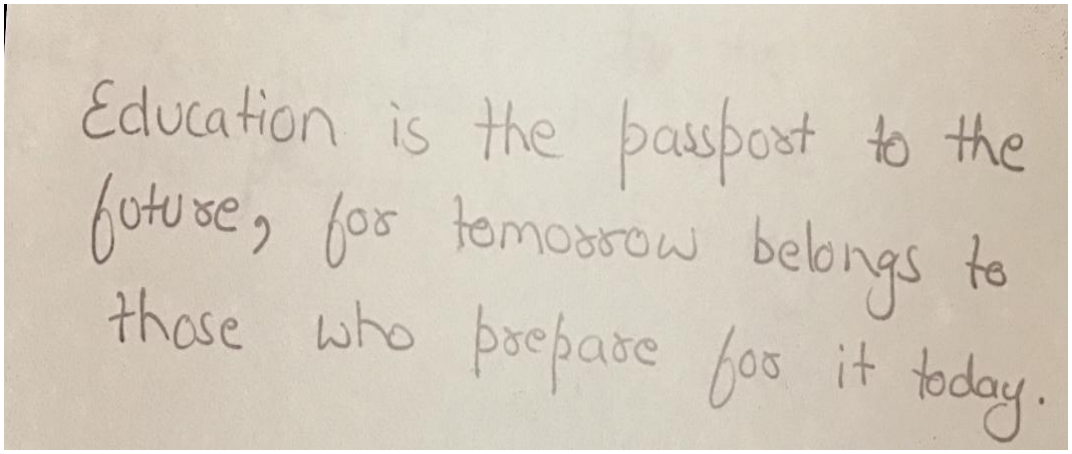
The invisible writing of both disappearing and erasable ink become visible when treated with the iodine crystals fumes.

Table 4.2: Results of examination of invisible writing by iodine fuming method.

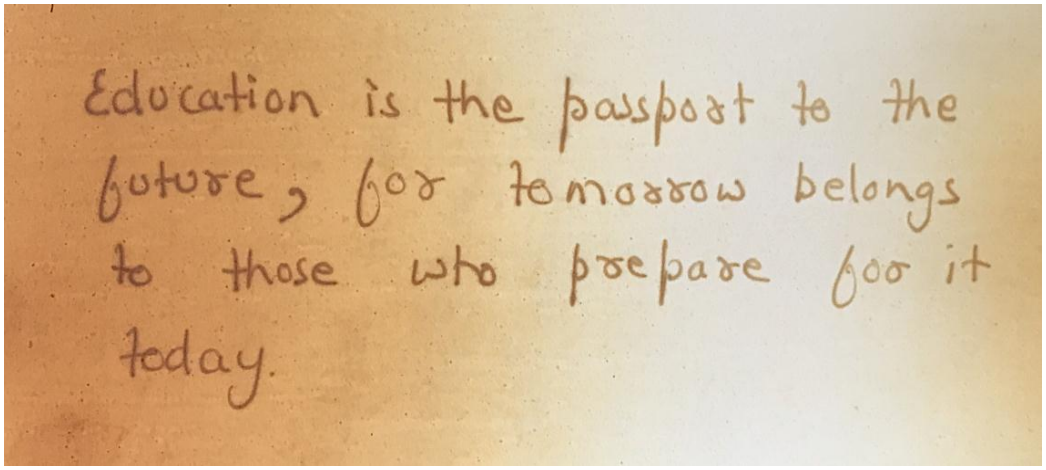
S.No.	Type of Ink	Type of paper	Examination Method	Result
1	Erasable	Copier	Iodine Fuming	Visible
2	Erasable	Bond	Iodine Fuming	Visible
3	Erasable	Glossy	Iodine Fuming	Visible
4	Disappearing	Copier	Iodine Fuming	Visible
5	Disappearing	Bond	Iodine Fuming	Visible
6	Disappearing	Glossy	Iodine Fuming	Visible



A- Copier Paper

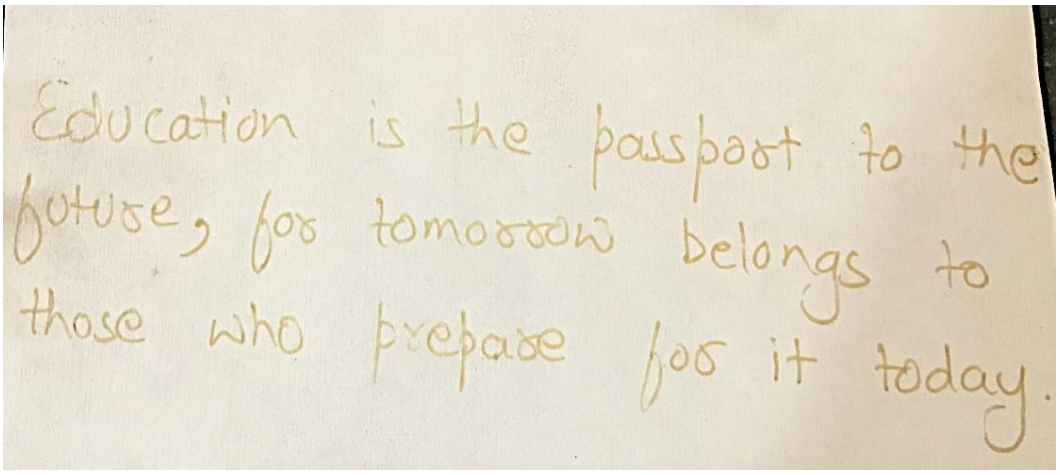


B- Bond Paper

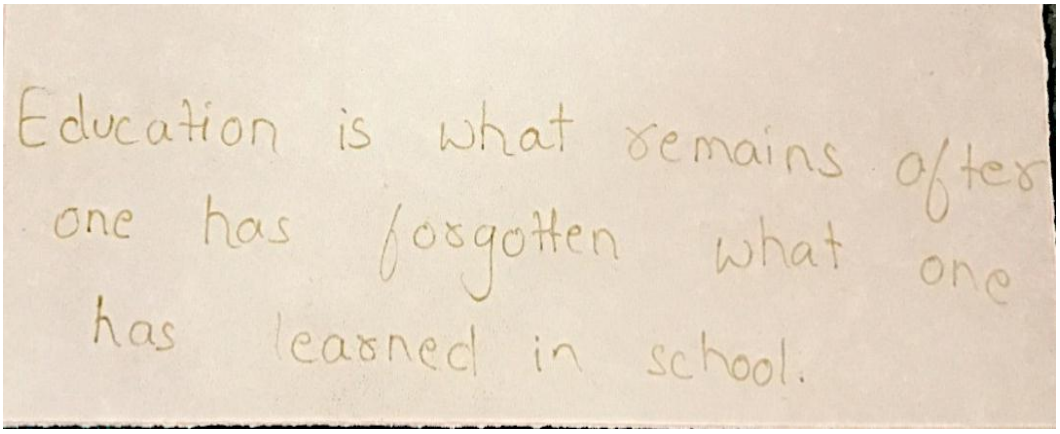


C- Glossy Paper

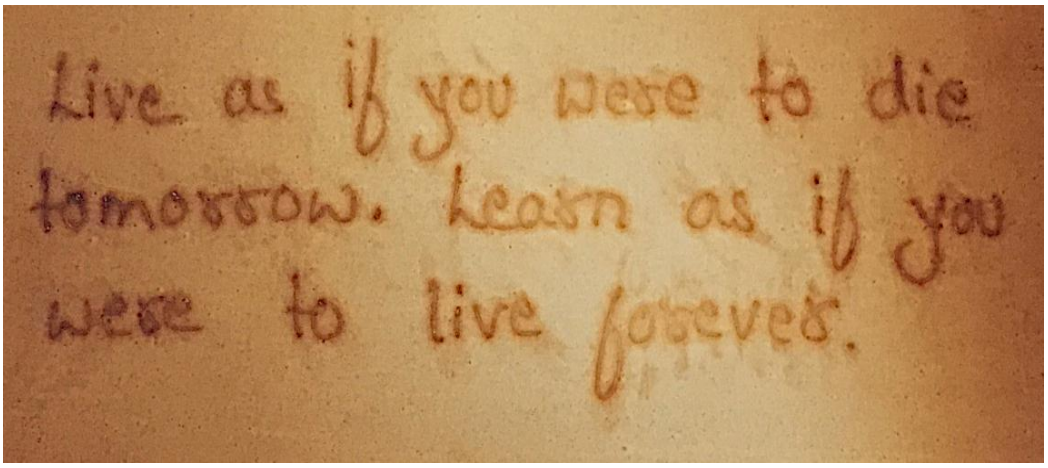
Figure 4.14: Reappeared writing of disappearing ink on A-copier paper, B-bond paper and C-glossy paper by Iodine Fuming Method.



A- Copier Paper



B- Bond Paper



C- Glossy Paper

Figure 4.15: Reappeared writing of erasable ink on A-copier paper, B-bond paper and C-glossy paper by Iodine Fuming Method.

4.4.4 Decipherment using Sodium hydroxide:

Total 300 samples were collected and examined, 150 sample for erasable ink (50 for each paper type) and 150 samples for disappearing ink (50 for each paper type).

The disappearing ink writing was visible when treated with the alkaline solution such as NaOH. 5% NaOH solution were applied over the disappeared handwriting written on the different kind of papers with the help of cotton bud. Similar results were obtained when KOH was used. Photograph of the deciphered writing must be taken immediately as it will be visible for a short time only. Photographs were taken with the digital camera. Erasable ink writing are not visible by this method.

Table 4.3: Results of examination of invisible writing by Sodium Hydroxide

S.No	Type of Ink	Type of paper	Examination Method	Result
1	Erasable	Copier	NaOH	Not Visible
2	Erasable	Bond	NaOH	Not Visible
3	Erasable	Glossy	NaOH	Not Visible
4	Disappearing	Copier	NaOH	Visible
5	Disappearing	Bond	NaOH	Visible
6	Disappearing	Glossy	NaOH	Visible

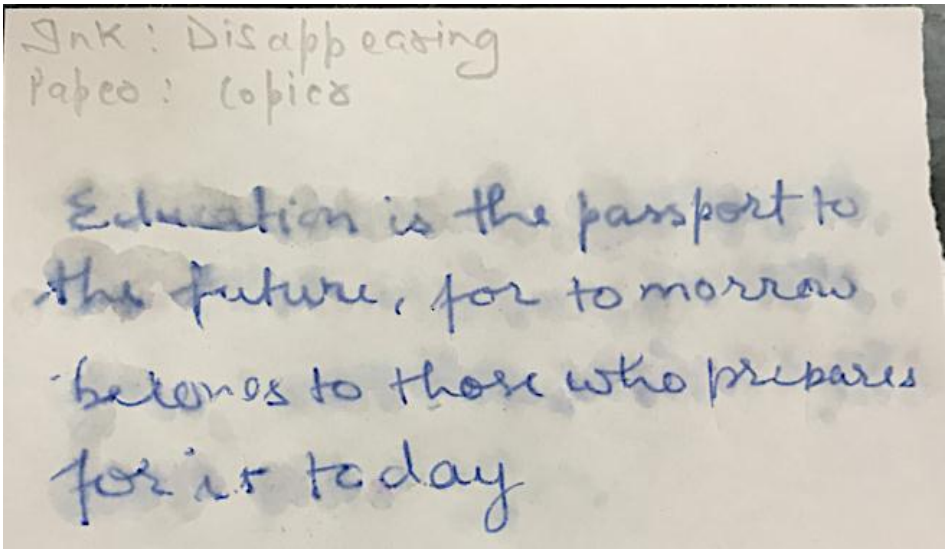


Figure 4.16: Reappeared writing of disappearing ink on copier paper by Sodium hydroxide method.

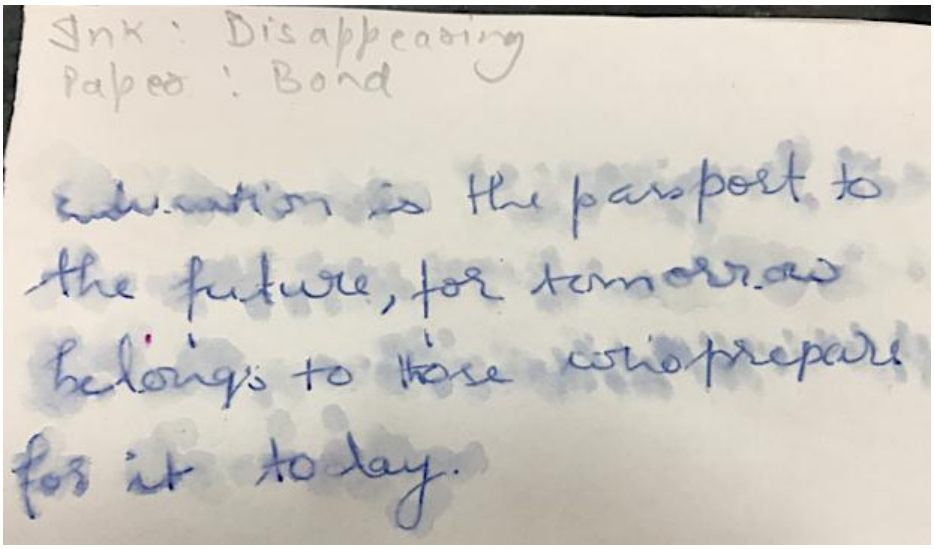


Figure 4.17: Reappeared writing of disappearing ink on bond paper by Sodium hydroxide method.

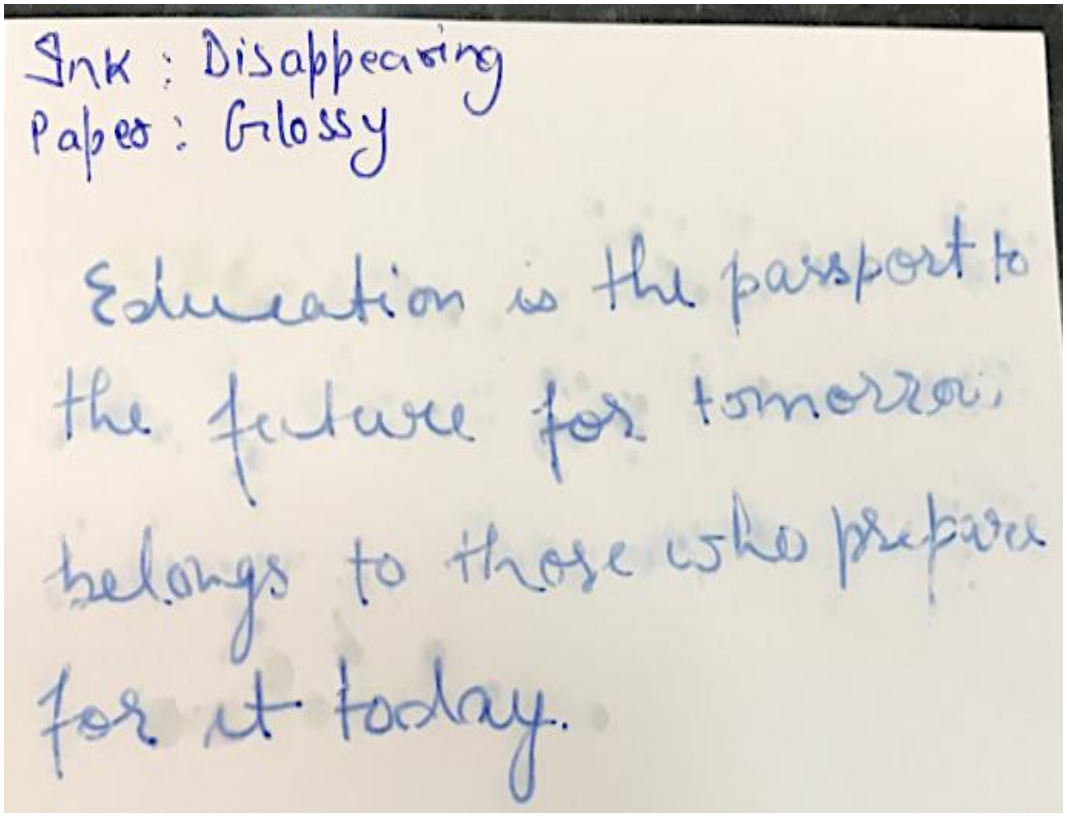


Figure 4.18: Reappeared writing of disappearing ink on glossy paper by Sodium hydroxide method.

4.4.5 Decipherment using Video Spectral Comparator-8000 (VSC)

VSC works on the basic principal of light. The samples were examined under at different wavelength of lights with different filters and intensity. The samples were placed under the instruments and the lights were applied on it. When the ink interacts with the light at any observable events resulted in the decipherment of invisible ink because of its optical phenomenon. Both thermochromic ink and disappearing ink writings can be decipher by using VSC-8000.

Thermochromic ink writings are visible under both U.V. light and Spot light whereas, disappearing ink writings are only clearly visible under the U.V. light of VSC-8000. Although disappearing ink does not give clear results under spot light but few traces of strokes are still visible. Disappearing ink when react with the carbon dioxide it leaves a white residue, which was invisible to the naked eyes but when examined under the instruments (UV light) it gives fluorescence(24). Instrumental analysis for the examination of questioned samples is the best way as it is the non-destructive technique and it does not affect the samples.

Total 450 samples were collected, 50 samples for each type of paper and ink colour. 50 samples for blue ink on copier paper, 50 samples for black ink on copier paper and 50 samples for red ink on copier paper. Similarly samples were prepared for bond paper and glossy paper.

All the samples were examined at CBI-CFSL, New Delhi.

Each line of all the samples is written by different brand of invisible ink:

- First line is written by using erasable Hamley Hamster pen
- Second line is written by using erasable Pilot pen
- Third line is written by using erasable Uniball pen
- Forth line is written by using disappearing ink pen (only in case of blue ink)

4.4.5.1 Results of Blue ink samples:

Table 4.4: Results of examination of Blue invisible ink writing by using VSC

BLUE INK													
S .No.		**Hamley Hamster**			**Pilot**			**Uniball**			**Disappearing ink**		
	Wave-length	**Copier**	**Bond**	**Glossy**	**Copier**	**Bond**	**Glossy**	**Copier**	**Bond**	**Glossy**	**Copier**	**Bond**	**Glossy**
	U.V. – Visible Light												
1	365nm	NV	PV	PV	V	V	V	PV	PV	PV	PV	NV	PV
2	312nm	PV	V	PV	V	V	V	V	V	V	V	V	V
3	254nm	V	V	V	V	V	V	V	V	V	V	V	V
	SPOT Light												
4	645nm	V	V	V	V	V	V	V	V	V	PV	PV	NV
5	665nm	V	V	V	V	V	V	V	V	V	PV	PV	NV
6	695nm	PV	PV	PV	PV	PV	PV	PV	PV	PV	PV	PV	PV
7	715nm	NV	NV	NV	NV	NV	NV	NV	NV	NV	NV	NV	NV
8	725nm	NV	NV	NV	NV	NV	NV	NV	NV	NV	NV	NV	NV
9	780nm	NV	NV	NV	NV	NV	NV	NV	NV	NV	NV	NV	NV
10	830nm	NV	NV	NV	NV	NV	NV	NV	NV	NV	NV	NV	NV

V - **Visible**
PV - **Partially Visible**
NV - **Not Visible**
SV - **Smudging Visible**

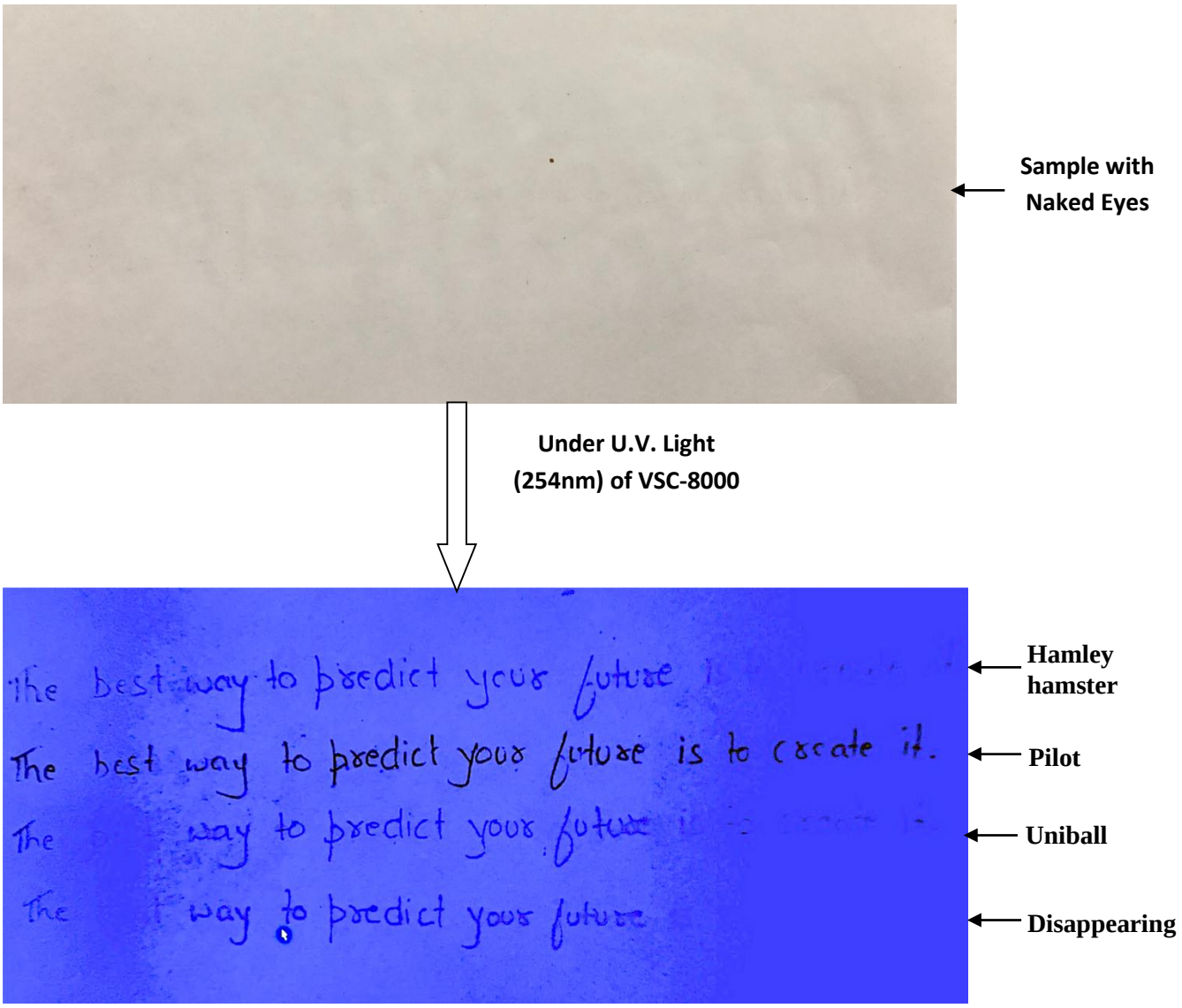


Figure 4.19: Erasable blue ink writing on copier paper visible under the U.V. light of VSC-8000

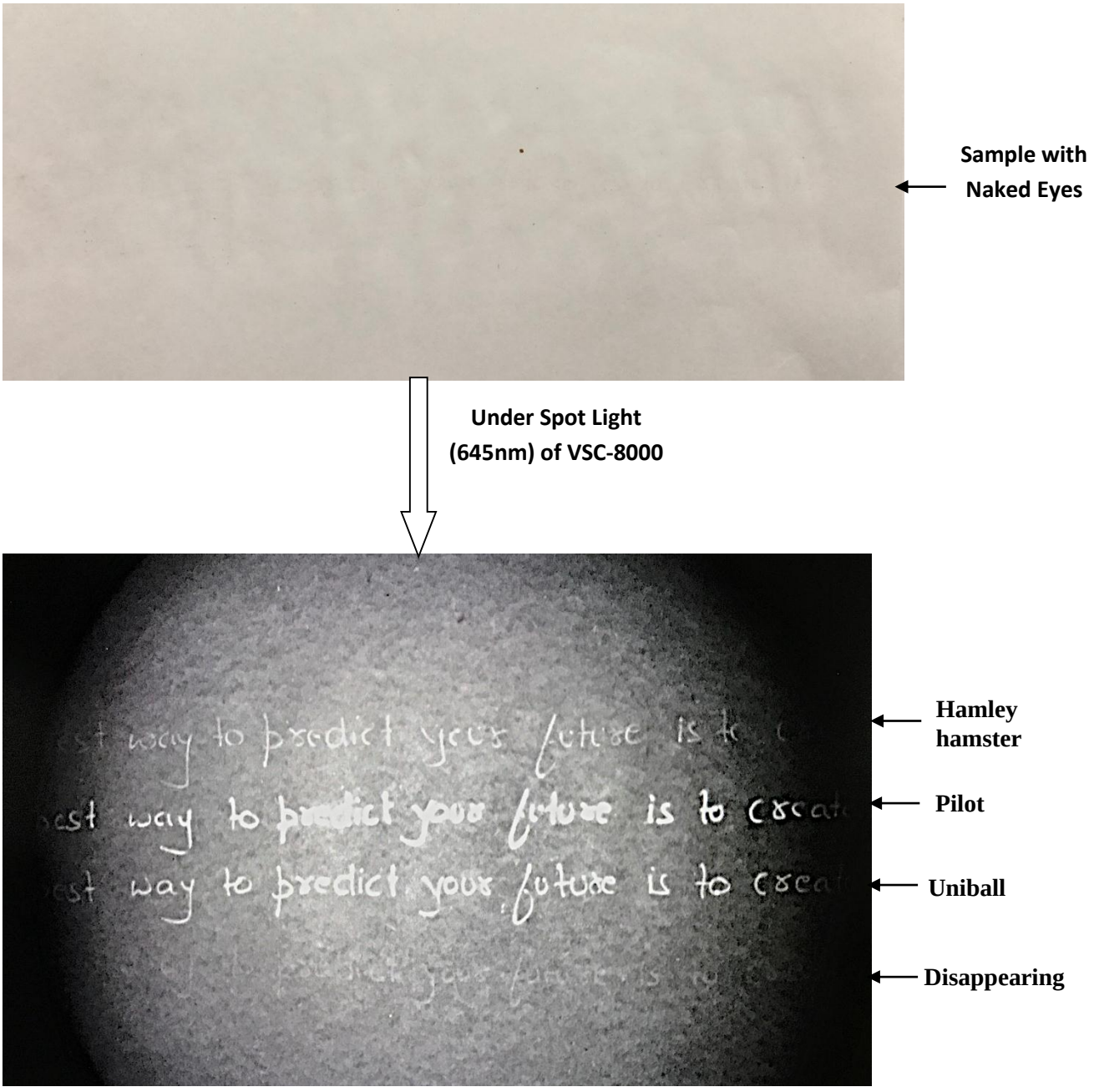


Figure 4.20: Erasable blue ink writing on copier paper visible under the spot light of VSC-8000

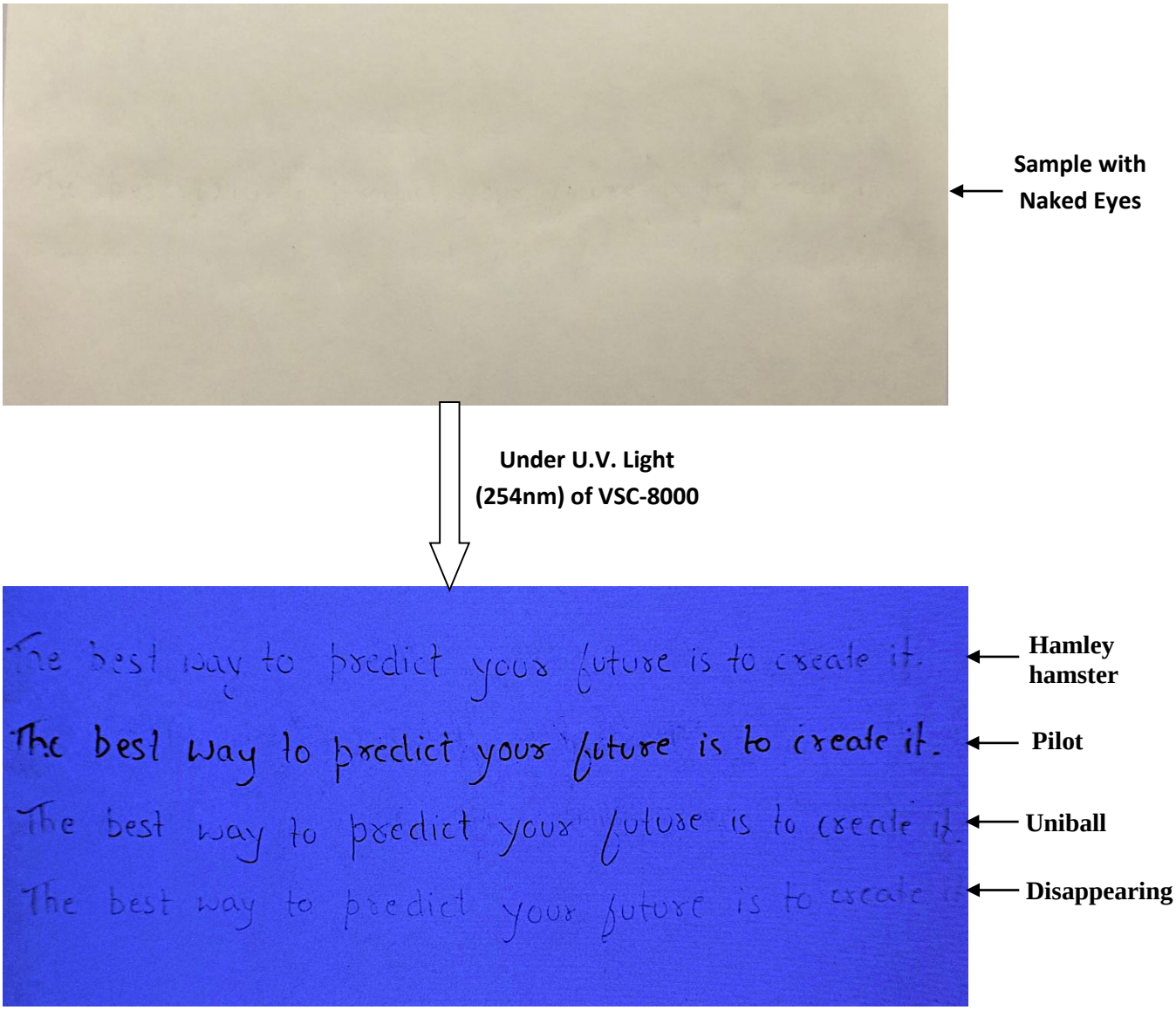


Figure 4.21: Erasable blue ink writing of bond paper visible under the U.V. light of VSC-8000

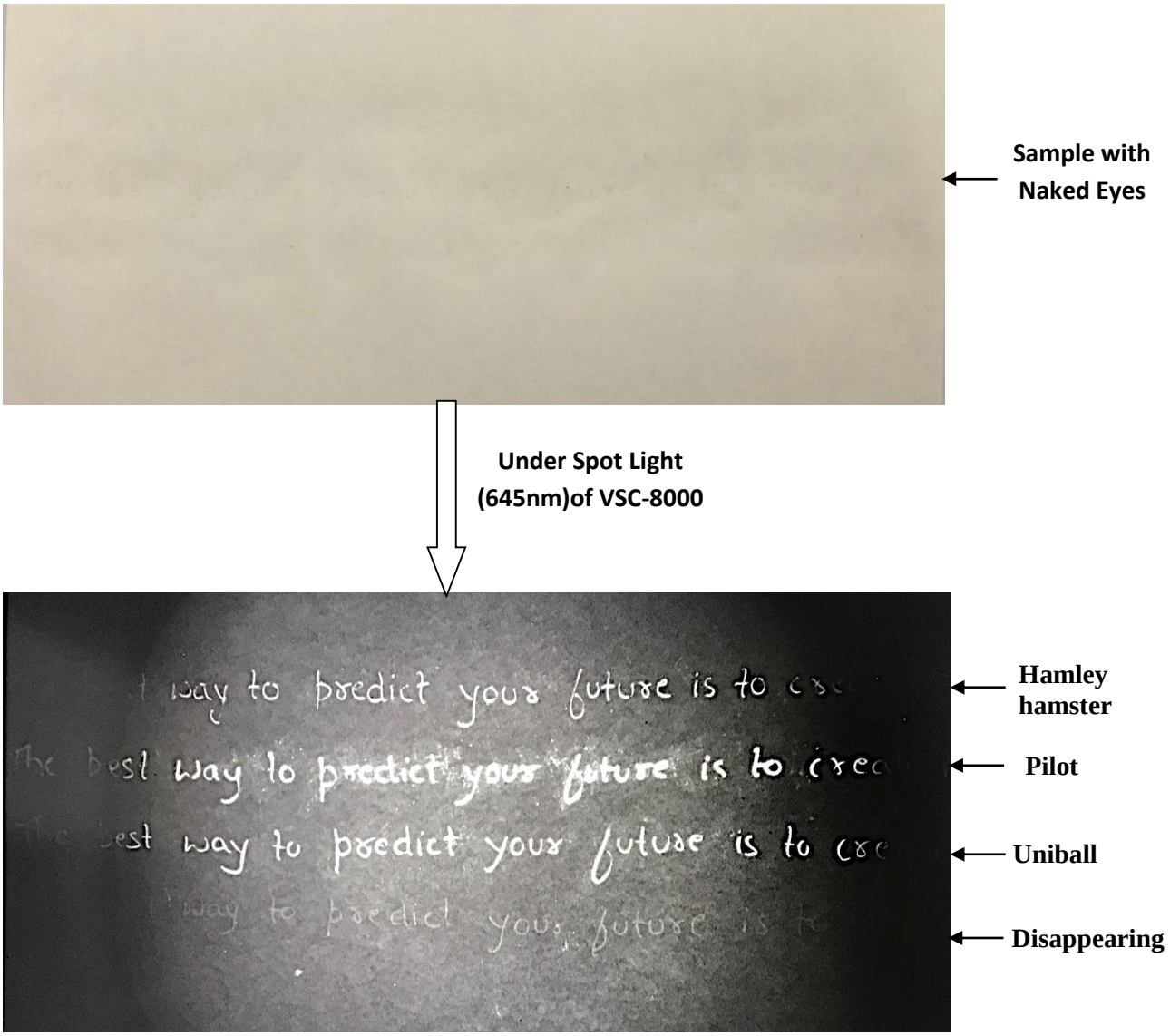


Figure 4.22: Erasable blue ink writing on bond paper visible under the spot light of VSC-8000

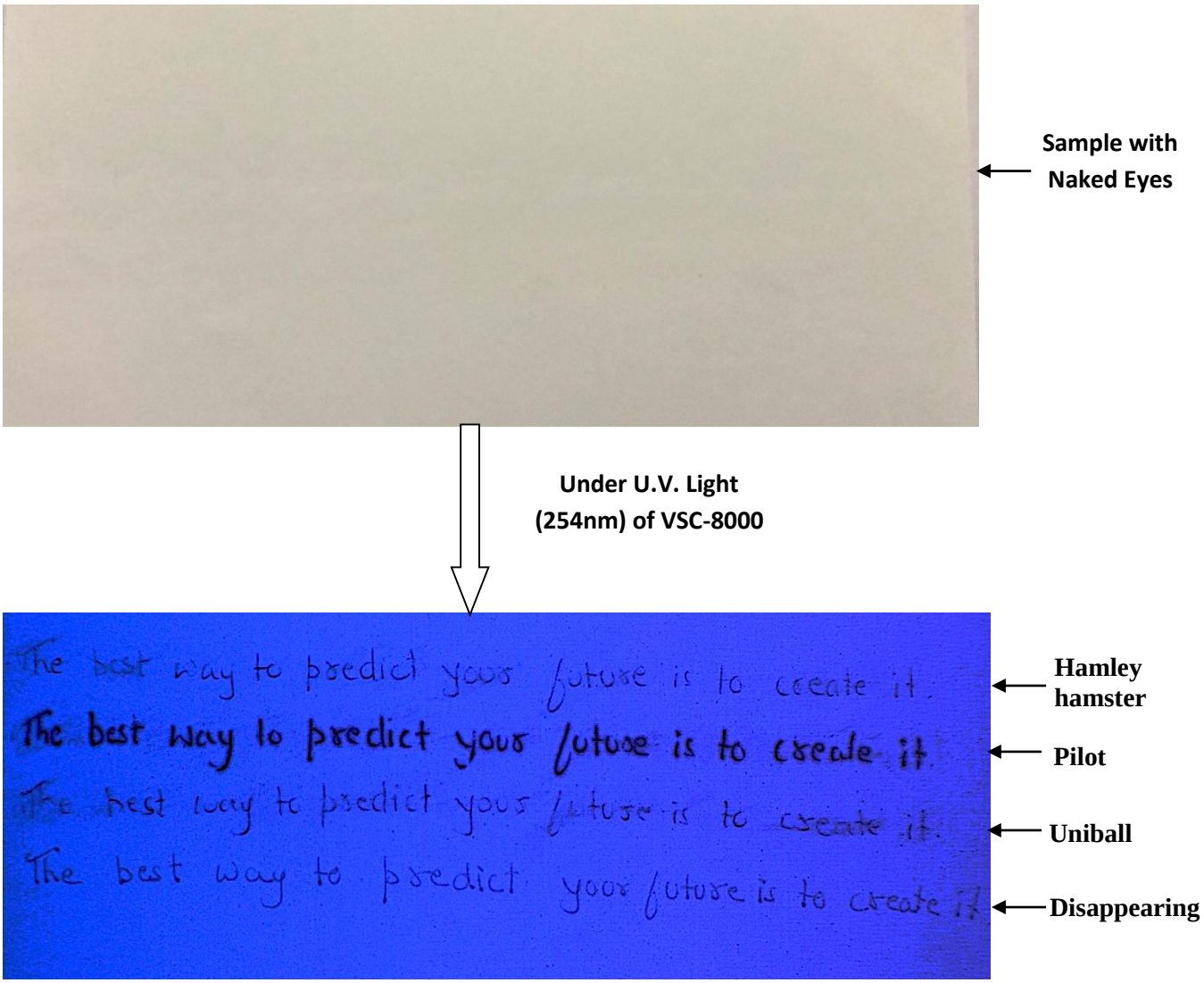


Figure 4.23: Erasable blue ink writing on glossy paper visible under the U.V. light of VSC-8000

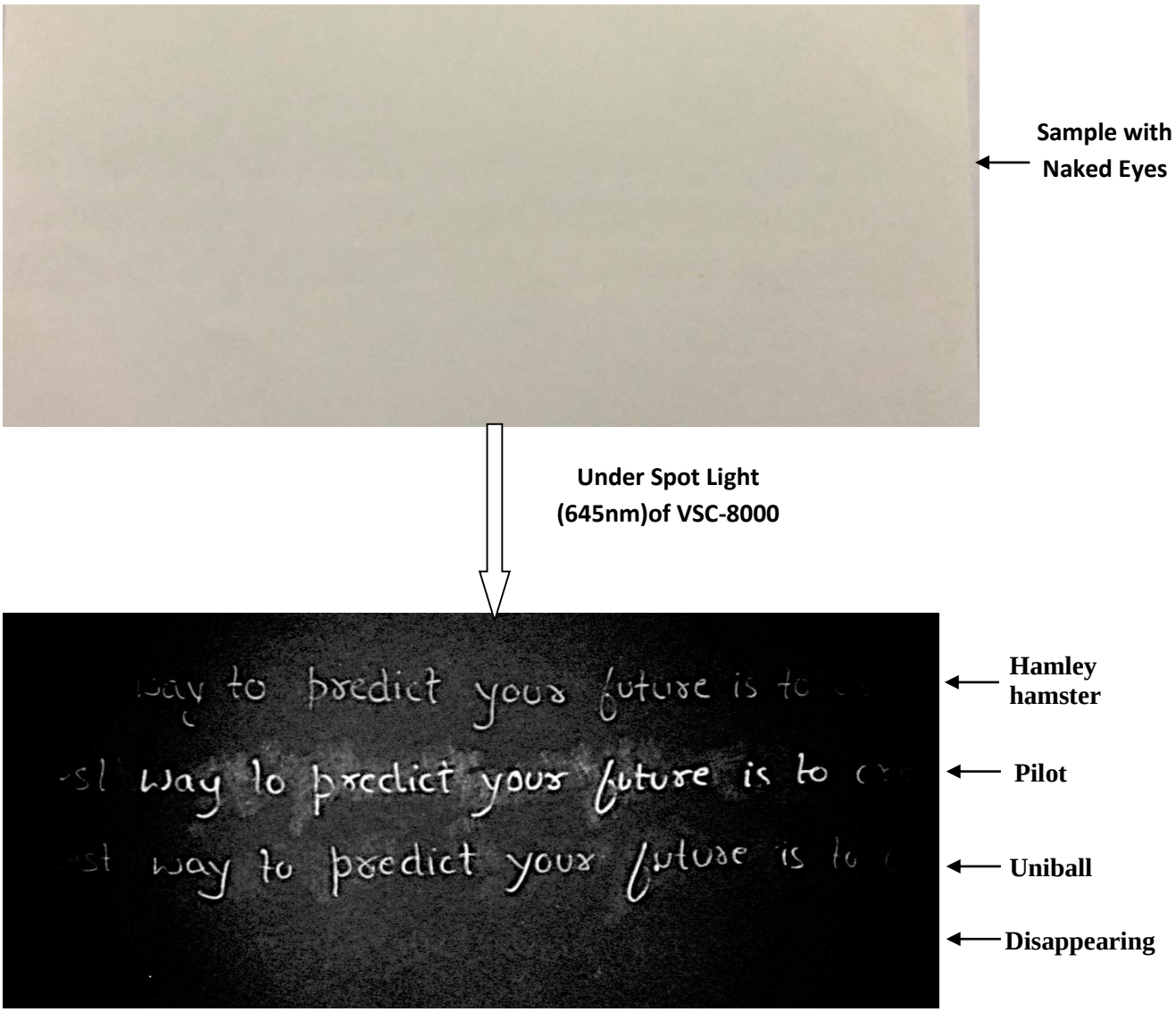


Figure 4.24: Erasable blue ink writing on glossy paper visible under the spot light of VSC-8000

4.4.5.2 Results of Black Ink Samples:

Table 4.5: Results of examination of Black invisible ink writing by using VSC

BLACK INK										
S.No.		Hamley Hamster			Pilot			Uniball		
	Wavelength	Copier	Bond	Glossy	Copier	Bond	Glossy	Copier	Bond	Glossy
	U.V. – Visible Light									
1	365nm	PV	PV	PV	V	V	PV	PV	PV	PV
2	312nm	V	V	V	V	V	SV	V	V	SV
3	254nm	V	V	V	V	V	V	V	V	V
	SPOT Light									
4	645nm	V	V	V	V	V	V	V	V	V
5	665nm	V	V	V	V	V	V	V	V	V
6	695nm	PV	PV	PV	PV	PV	PV	PV	PV	PV
7	715nm	NV	NV	NV	NV	NV	NV	NV	NV	NV
8	725nm	NV	NV	NV	NV	NV	NV	NV	NV	NV
9	780nm	NV	NV	NV	NV	NV	NV	NV	NV	NV
10	830nm	NV	NV	NV	NV	NV	NV	NV	NV	NV

V - **Visible**
PV - **Partially Visible**
NV - **Not Visible**
SM - **Smudging Visible**

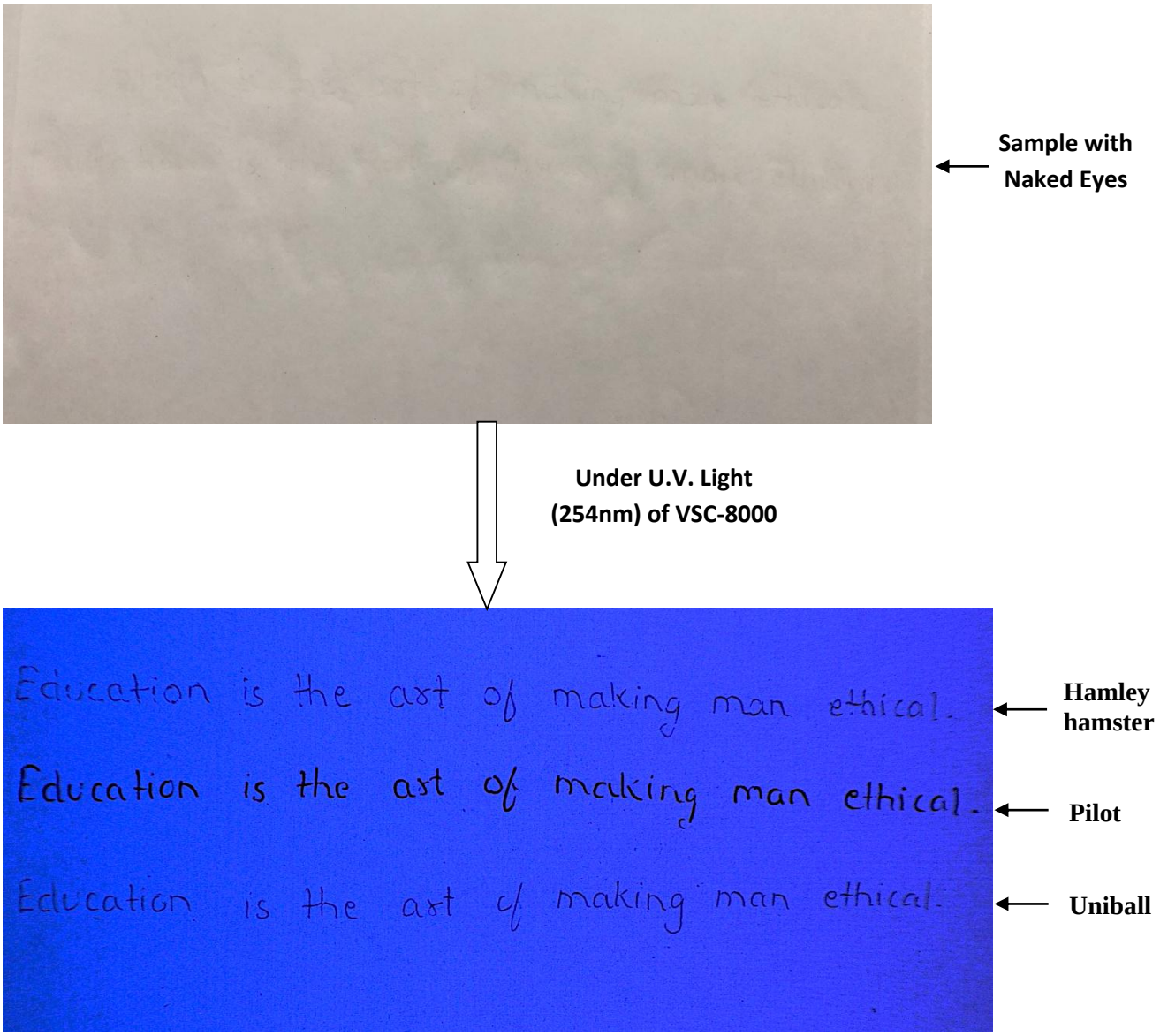


Figure 4.25: Erasable black ink writing on copier paper visible under the U.V. light of VSC-8000

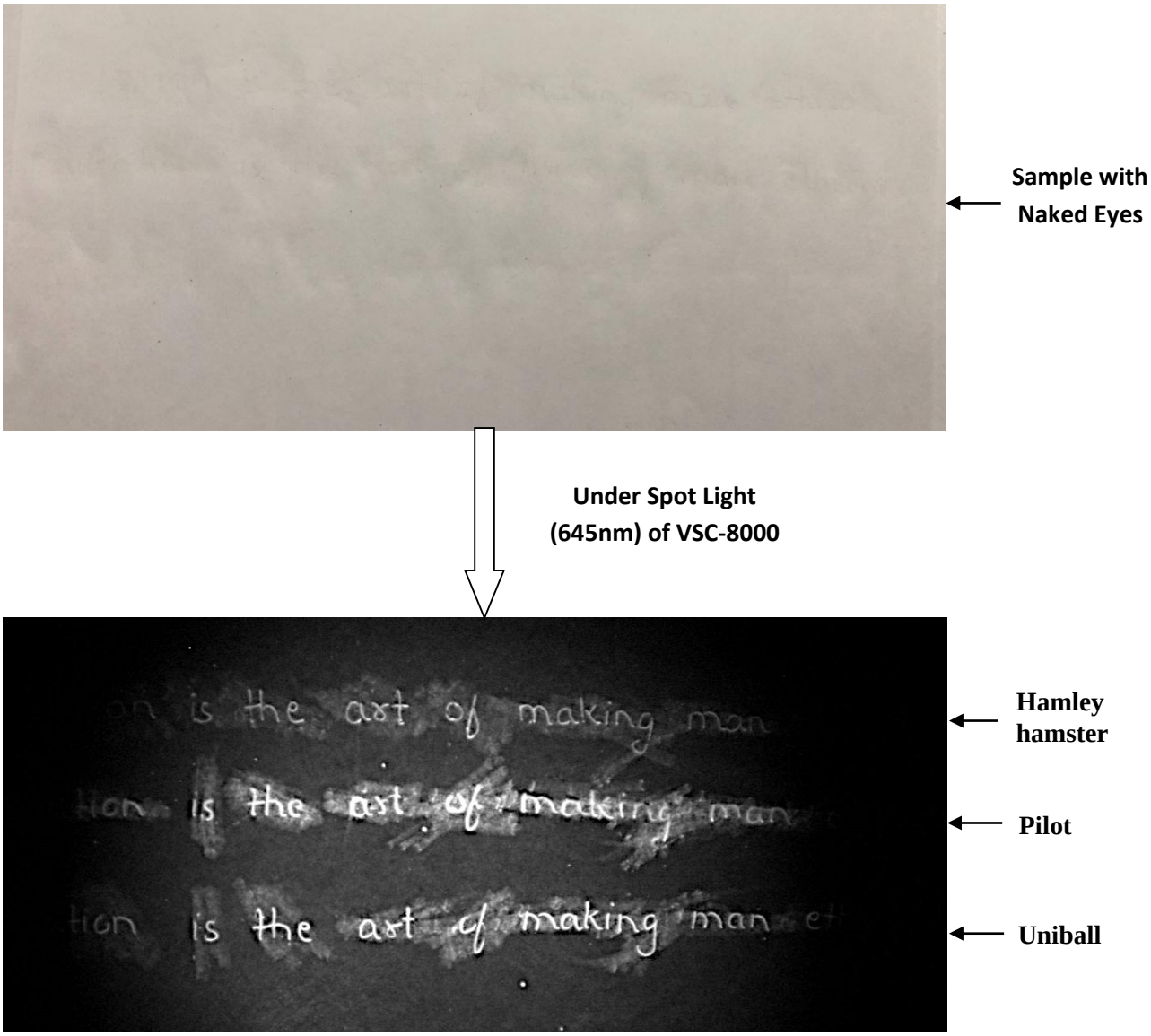


Figure 4.26: Erasable black ink writing on copier paper visible under the spot light of VSC-8000

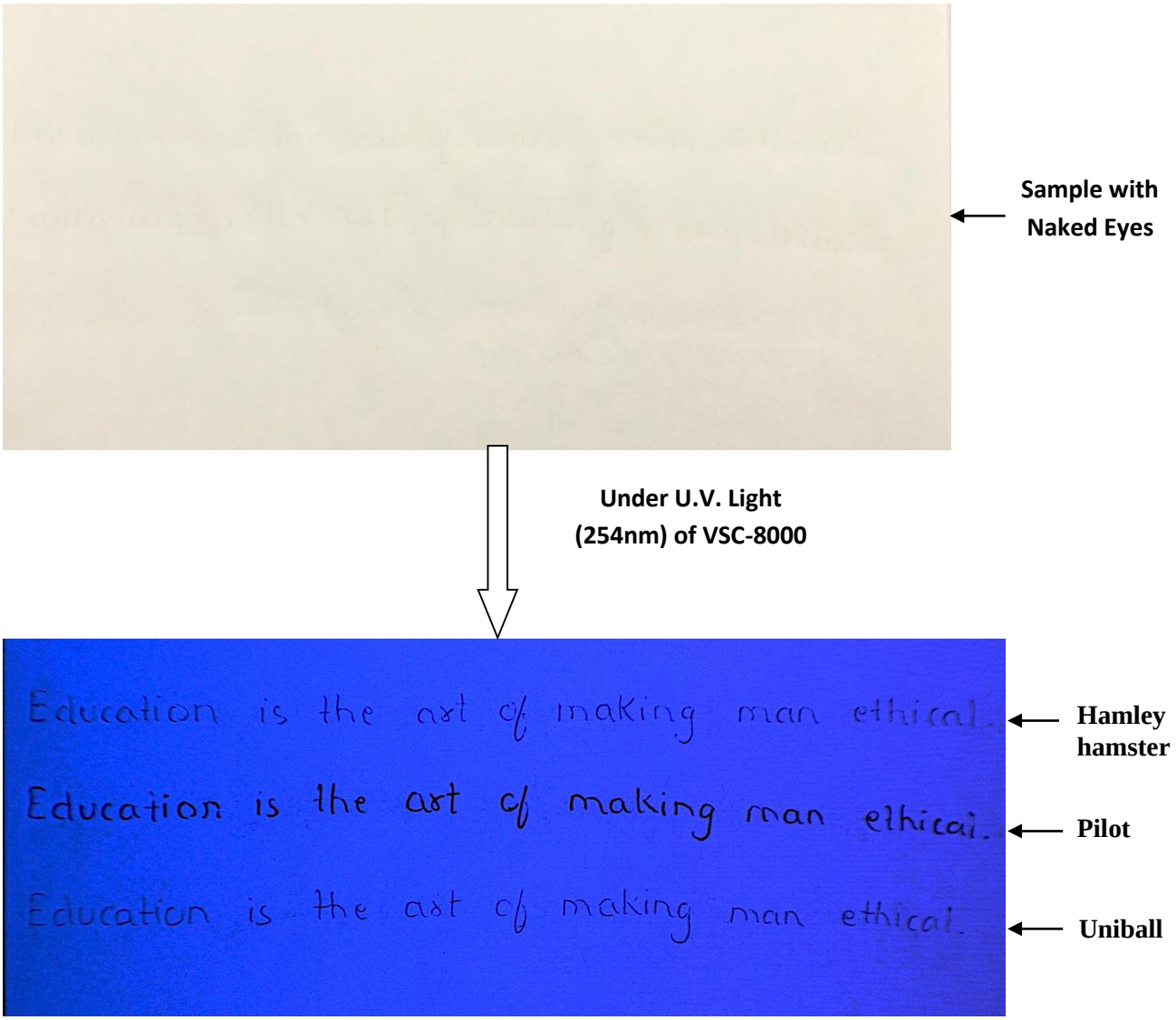


Figure 4.27: Erasable black ink writing on bond paper visible under the U.V. light of VSC-8000

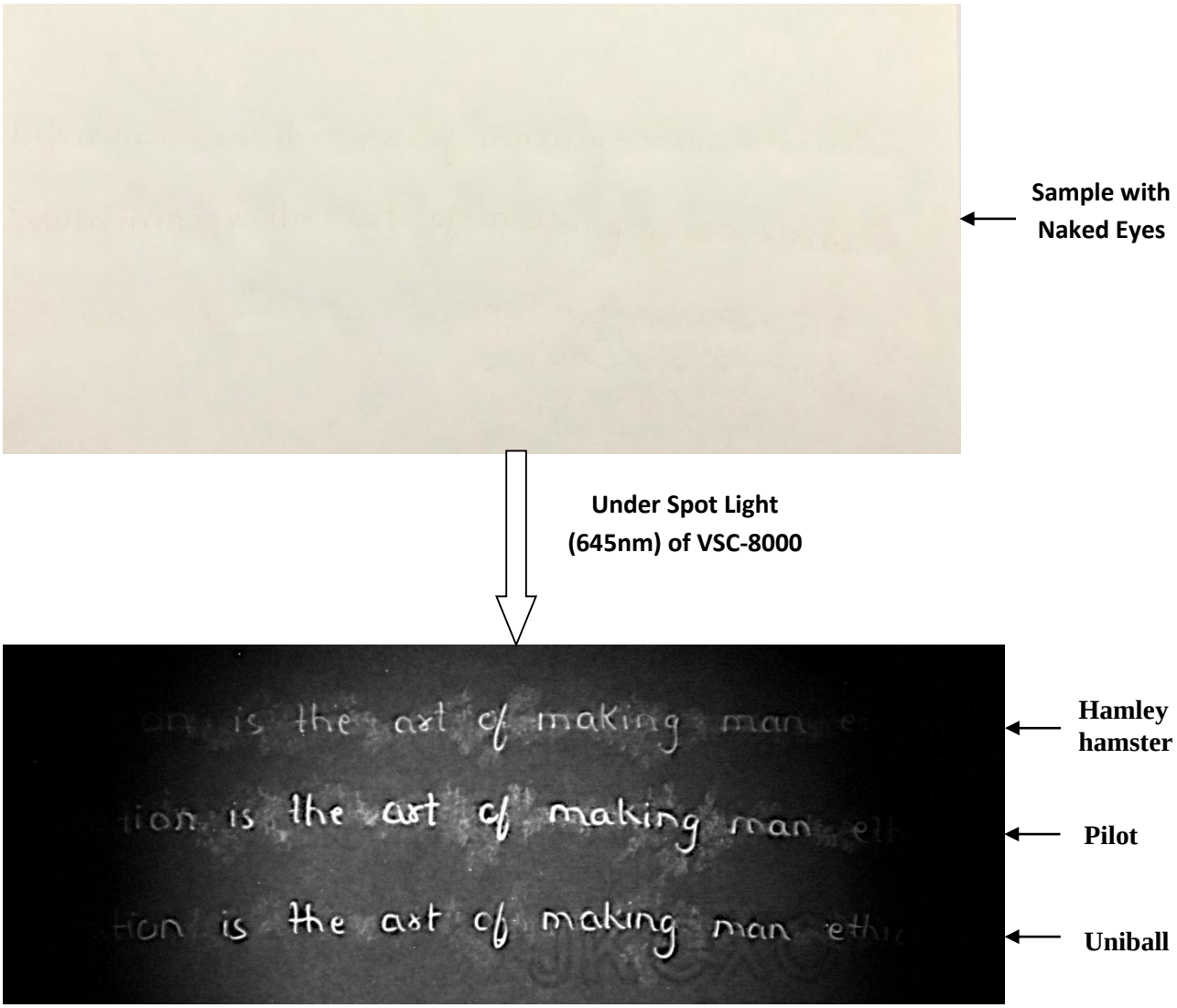


Figure 4.28: Erasable black ink writing on bond paper visible under the spot light of VSC-8000

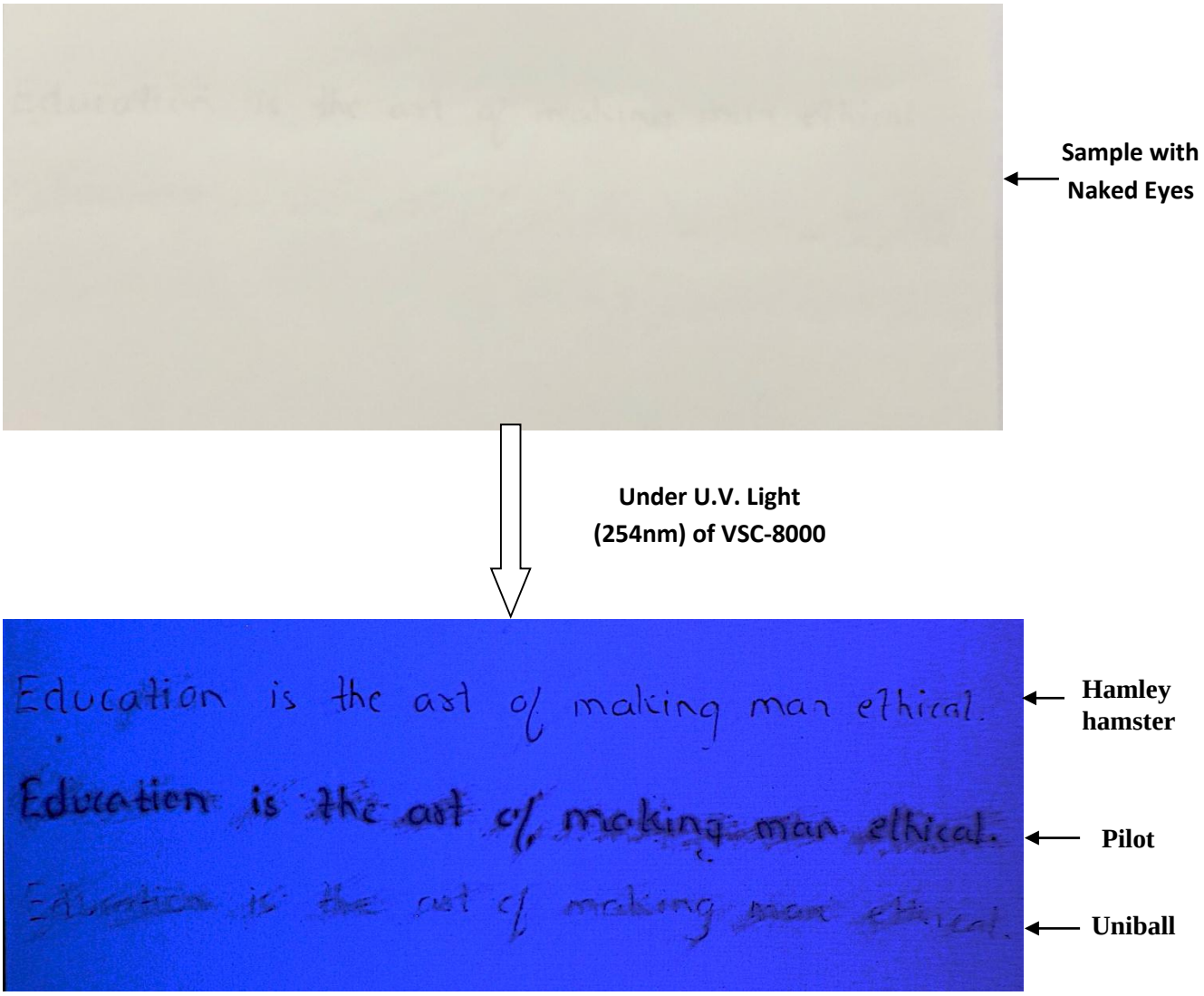


Figure 4.29: Erasable black ink writing on glossy paper visible under the U.V. light of VSC-8000

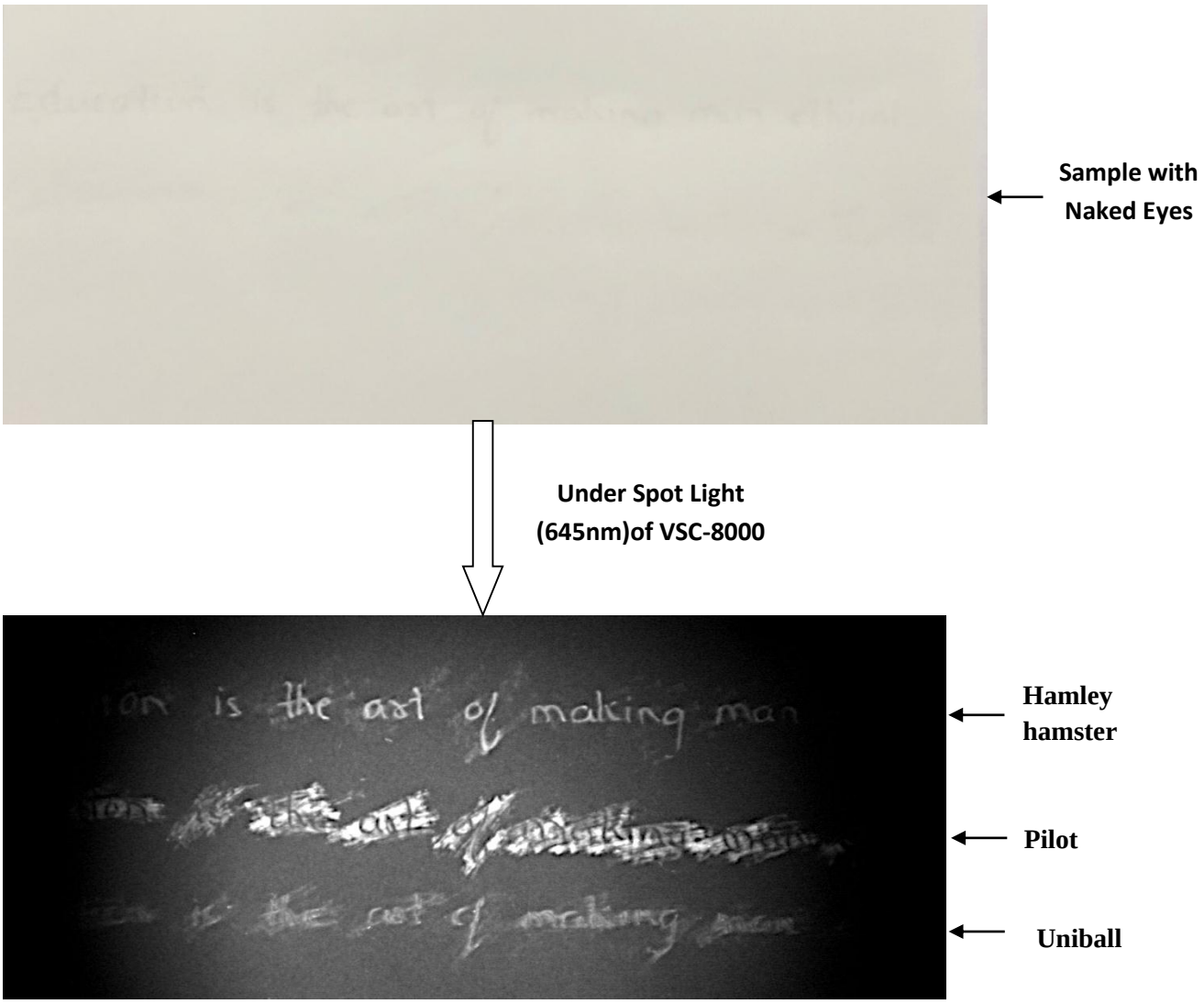


Figure 4.30: Erasable black ink writing on glossy paper visible under the spot light of VSC-8000

4.4.5.3 Results of Red Ink Samples:

Table 4.6: Results of examination of Red invisible ink writing by using VSC

RED INK										
S.No.		Hamley Hamster			Pilot			Uniball		
	Wavelength	Copier	Bond	Glossy	Copier	Bond	Glossy	Copier	Bond	Glossy
	U.V. – Visible Light									
1	365nm	NV	NV	NV	V	V	V	PV	PV	PV
2	312nm	PV	PV	PV	V	V	V	V	V	V
3	254nm	V	V	VV	V	V	V	V	V	V
	SPOT Light									
4	645nm	SV	V	SV	SV	V	SV	SV	V	SV
5	665nm	SV	SV	SV	SV	SV	SV	SV	SV	SV
6	695nm	PV	PV	PV	PV	PV	PV	PV	PV	PV
7	715nm	NV	NV	NV	NV	NV	NV	NV	NV	NV
8	725nm	NV	NV	NV	NV	NV	NV	NV	NV	NV
9	780nm	NV	NV	NV	NV	NV	NV	NV	NV	NV
10	830nm	NV	NV	NV	NV	NV	NV	NV	NV	NV

V - **Visible**
PV - **Partially Visible**
NV - **Not Visible**
SM - **Smudging Visible**

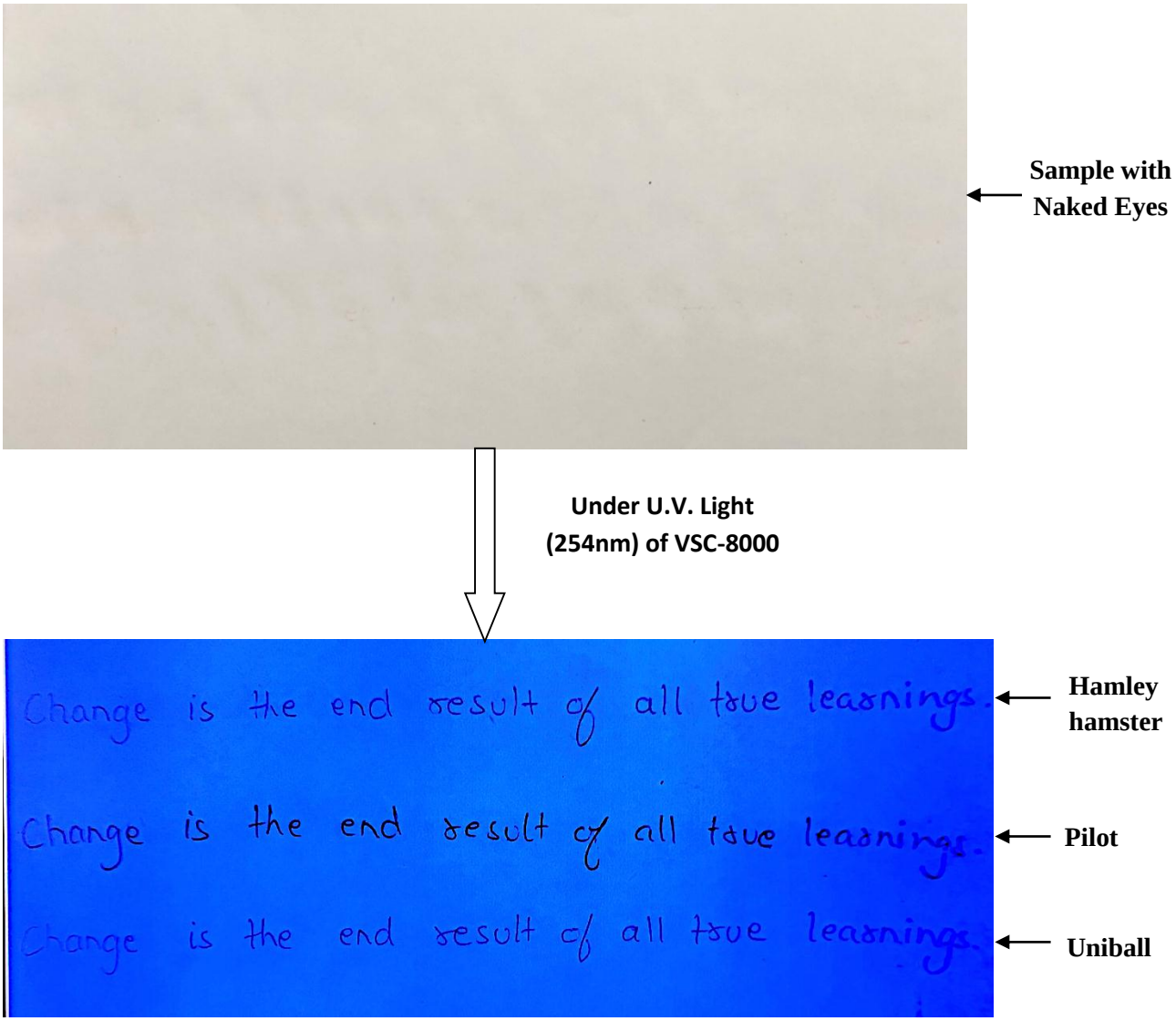


Figure 4.31: Erasable red ink writing on copier paper visible under the U.V. light of VSC-8000

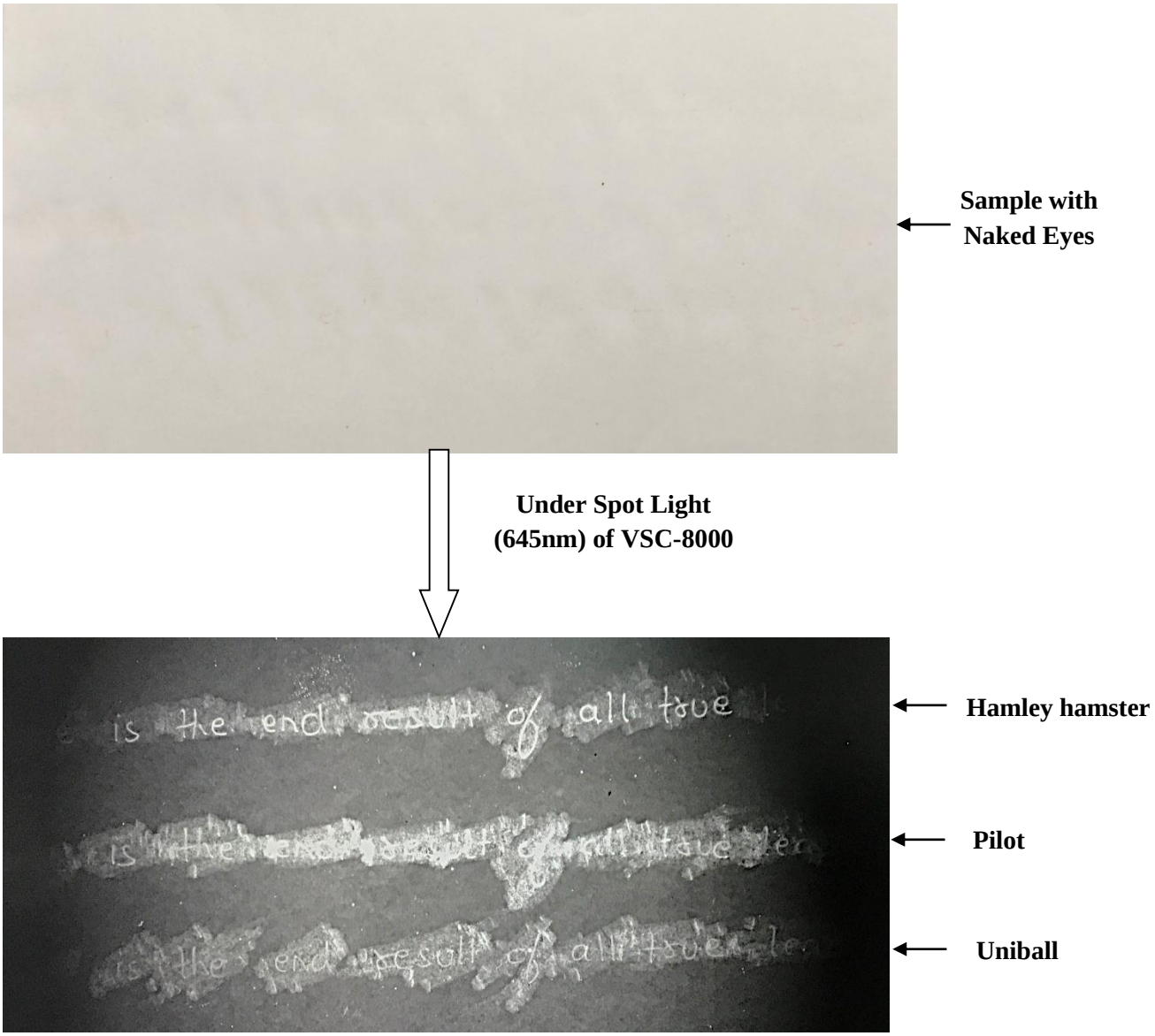


Figure 4.32: Erasable red ink writing on copier paper visible under the spot light of VSC-8000

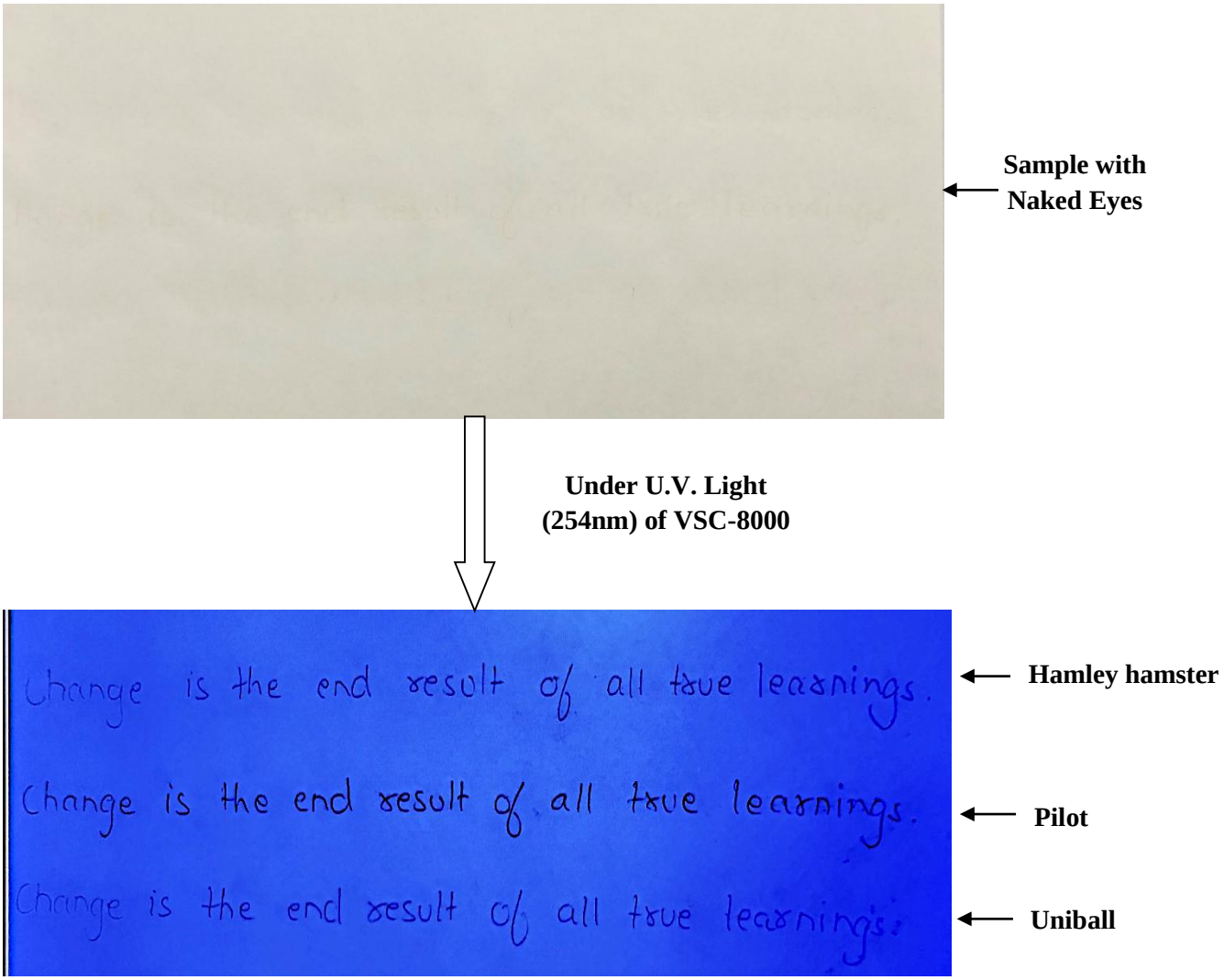


Figure 4.33: Erasable red ink writing on bond paper visible under the U.V. light of VSC-8000

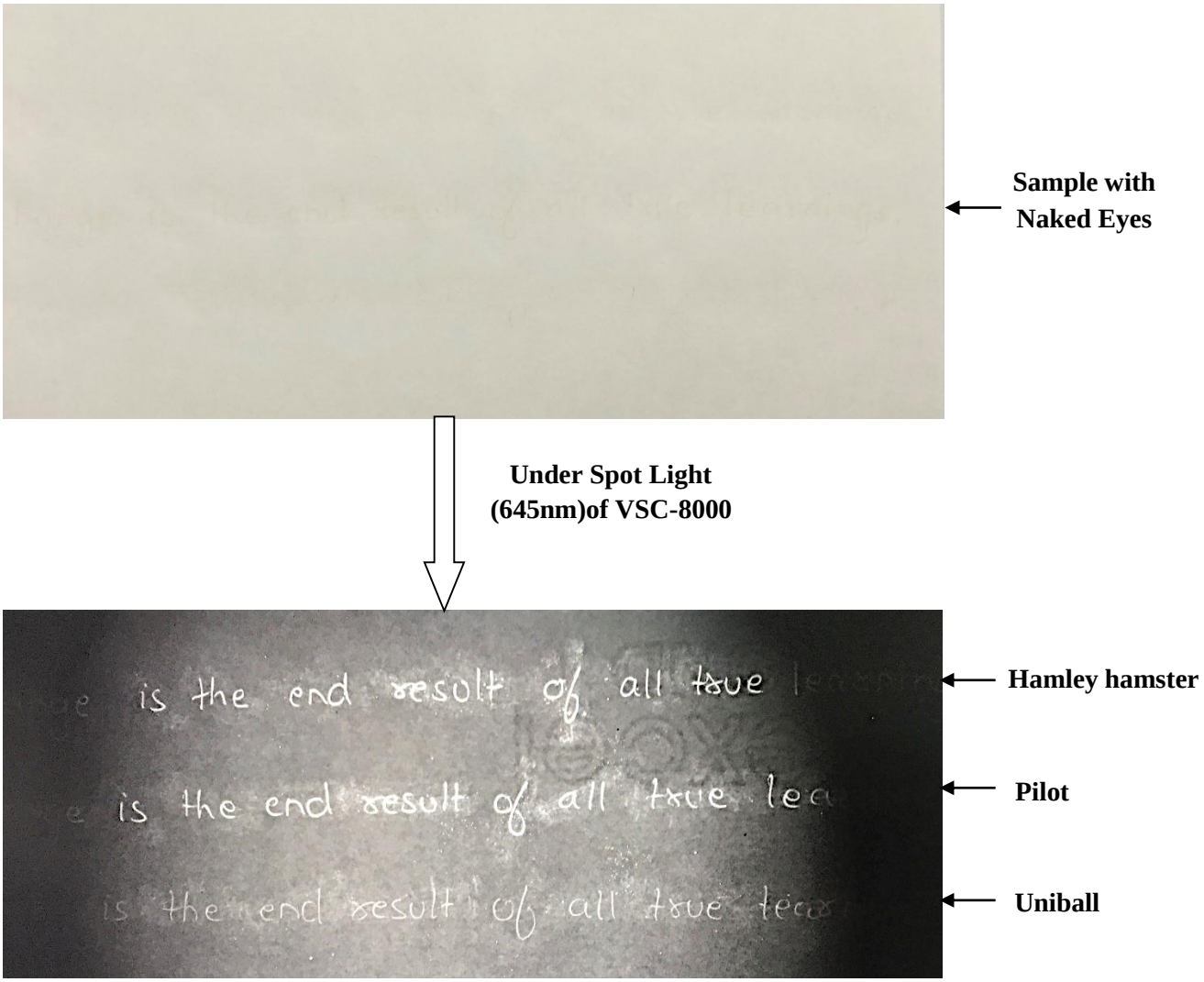


Figure 4.34: Erasable red ink writing on bond paper visible under the spot light of VSC-8000

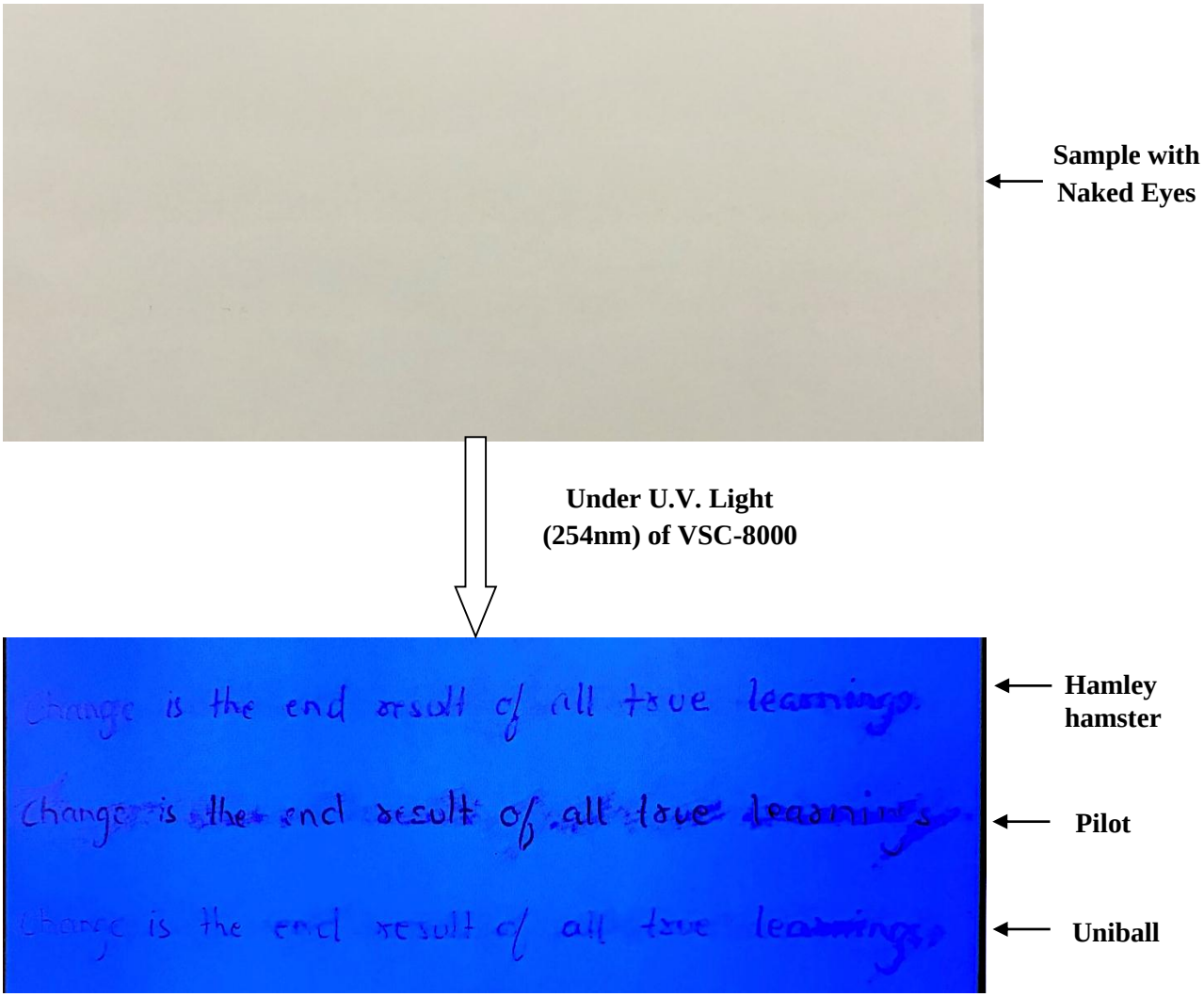


Figure 4.35: Erasable red ink writing on glossy paper visible under the U.V. light of VSC-8000

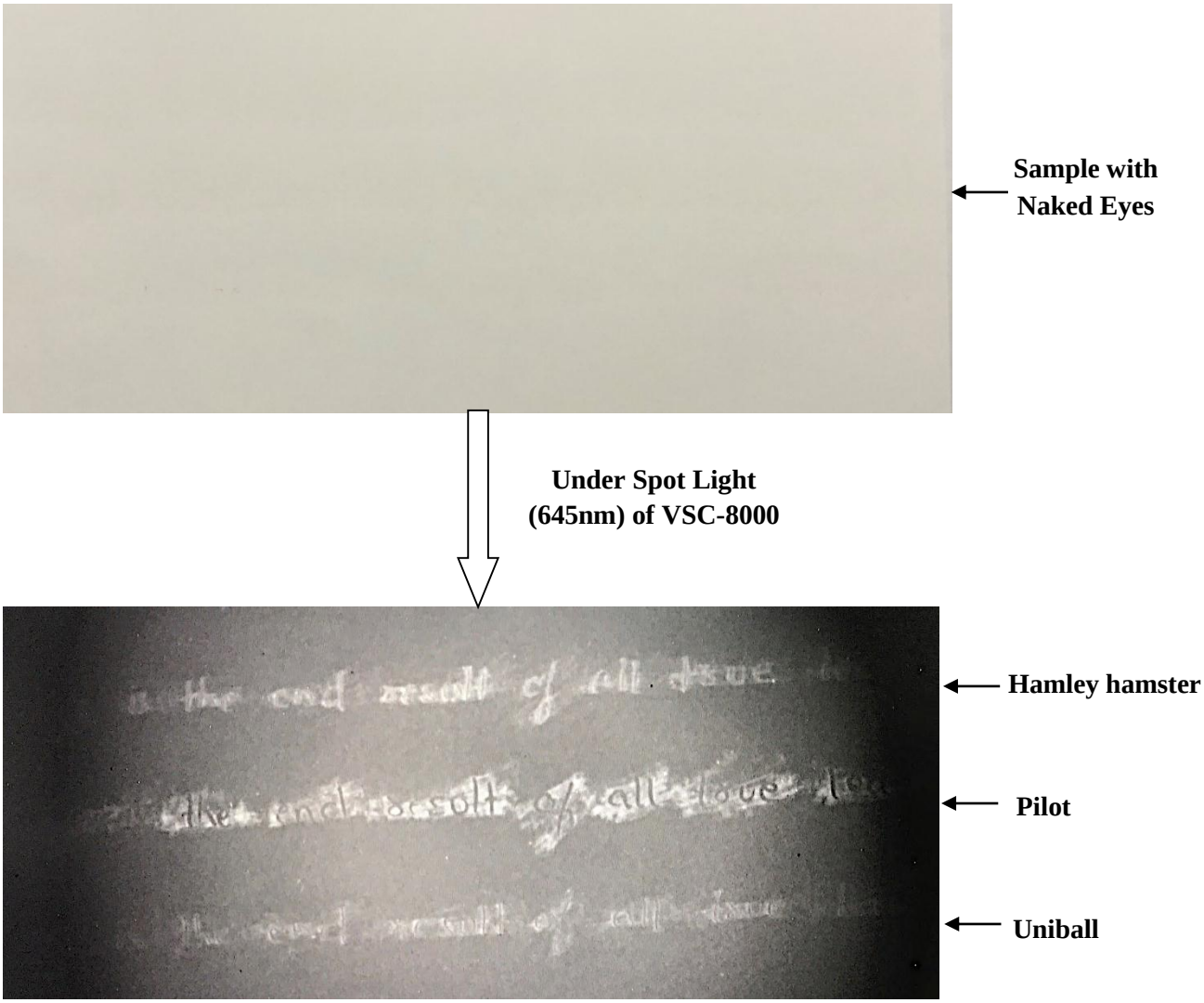


Figure 4.36: Erasable red ink writing on glossy paper visible under the spot light of VSC-8000

Writing of both ink are visible under the spot light and U.V. light of VSC-8000 on all three variety of paper. Smudging effect of erasable ink pen rubber erasure was also visible when glossy paper was used.

4.5 Conclusion:

It is difficult to detect disappeared invisible ink writings by naked eyes. Due to easy availability and unique properties of thermal inks various cases of criminal activities are reported across the globe.

Analyzing the samples by using phone flash light and Adobe Photoshop software can be used to decipher all the writing including disappearing ink writings.

It was observed that when a person writes with extremely light pressure then it becomes a little difficult to decipher writings on bond paper because erasing method cause a larger damage to the fibres of bond paper.

It was also observed that the disappearing ink writings become visible at only long U.V. whereas erasable ink writings were visible at both long and short U.V. light on all varieties of papers.

Chemical examination reveals that iodine fuming method can be used to decipher both erasable and disappearing ink lines. Sodium hydroxide (NaOH) or KOH method can only be use to decipher disappearing ink lines.

Video spectral comparator can be used to restore invisible ink writings on all variety of paper. It was observed that in some cases smudging effect was too loud to read the erased writing. Although it is difficult to read the erased writing due to the smudging effect but it can be established that something was written at that place which was erased.

CHAPTER – 5

TO DETECT THE ALTERATION IN PAPER DUE TO ERASURE

5.1 Introduction

Tampered documents are those in which some kind of alterations is done. Alteration can be defined as any kind of change in a document which makes it different from the original one. Sometimes these alterations are genuine but sometimes these are done with the intend to defraud. Tampering of original documents are of many types like it can be done by using erasures, addition, obliteration, invisible writing, indented writing, etc. Alteration in a document is done in such a way that they may remain unnoticed by the forensic document examiner (83). These documents need to be analysed thoroughly by the forensic document examiner to detect which type of tampering is done (152).

Alterations in a document are of many different types. Alterations can be done by addition also called as interlineation, erasures, obliterations, overwriting etc. Every document need to be analysed carefully to detect which type of tampering or alterations is done in that particular document (3).

5.2 Types of alteration in a document:

1. Additions:

Addition in a document is done when a letter, word, digit etc. is inserted which changes the meaning or information of the document. When such additions are done after the document is signed and without the consent or knowledge of the other party than it becomes fraudulent. In order to ascertain whether a addition in a document is genuine or false, document expert need to carefully examine the document. In case of additions or insertions it was found that if large space is available then the forger try to add large size letters to cover up the remaining space and if small space is available then the forger try to write small size letter and the writing will appear cramped (3). A microscopic examination need to be done to examine the following:

- same ink or different ink,
- the edges of strokes,
- pen strokes
- pen lifts need to be examined,
- shaded and un-shaded portions,
- size of letters.

2. Interlineations:

Interlineations are another type of alteration done by the forgers in documents. These can be defined as writing between lines of any instrument with intend to add information or may be correcting the written one. These can be examined by minutely examining the colour of the ink, sequence of strokes or crossing strokes, size of letters, slant of the letters, spacing between letter, words or lines etc. The fraudulent writing are likely to be differ from the adjacent original writing in different aspects mentioned above.

3. Sheet Insertion:

Sheet insertion is another type of alteration done by the forgers. If a page from a document is removed and substituted with another page that contain different information and convey different meaning is considered as a fraud. This can be examined by examining the paper and its characteristics like thickness, colour, shade and water-mark. One can also examine the ink of the writing, check if binding is damaged, characters of the letters etc. In case of printed documents size, shape and design of the type should be examined.

4. Obliteration:

Blotting out or smearing over of some contents of a document to make the original invisible or a document in which something is removed deliberately by masking with a writing instrument or overwriting is called obliteration, that document in which obliteration is done is called as a tempered document. Successful decipherment or restoration depends principally upon the medium used for the original handwriting and the covering material. Two possible methods of solution to penetrate the writing layer is photograph so that the original writing lying beneath is thus revealed. Second method is by studying the impression from the original writing or typewriting that has not been destroyed by the obliterating action.

Photographic method can give positive results only if the difference in colour or chemical composition exists between the original writing and the covering material. Separation may be affected by photographic filters of a colour similar to the obliterated material. One can also try to read the original writing by viewing of the back of the sheet under IR luminescence under different filters (144).

It is a very difficult task for the forensic document examiners to detect and restore obliterated writings. We can use visible or infrared spectroscopy to restore such writings. Different types of instruments are available which can be used decipher such types of obliterated writings. Decipherment or detection of such writings can be done under transmitted light, IR luminescence, visible light, UV light by using different variants of video spectral comparator (VSC) and projectina.

5. Overwriting:

Overwriting is very common and can be genuine or fraudulent. Sometimes a writer genuinely overwrite to correct a spelling mistake or correct a figure but in such cases overwriting is done boldly and no efforts was done to conceal the overwriting instead it is done carelessly. In case of fraudulent overwriting every effort is made to conceal the changes and it was done very carefully. Examination of overwriting can be done by examining the different ink and sequence of strokes. Various light source like direct light, oblique light, transmitted light and microscope can be used to detect any overlapping, corrections, careful joining of letters, touch ups and different ink. U.V. light and I.R. light can also be used for the examination purpose. The examiner must examine the back of the paper because overwriting are done carefully and slowly by applying heavy pen pressure which cause embossing at the back of the paper. This can reveal a lot if examined minutely (144).

6. Erasures:

Removal of something, a letter, word, symbol or a line from the original document is called erasure. Erasures are generally of two types:

- Physical erasure and
- Chemical erasure (152).

Physical erasures also called as mechanical erasure are those in which something is removed from the original document by using any erasure or a sharp object. These erasure cause abrasions or scratching on the surface which leaves much more definite tell -tale traces consisting of disturbed fibres of paper, indented marks and some portion of original strokes that were not removed completely in some cases. Rubber erasure incorporated at

the tip of each erasable pen is also a physical erasure. A forensic expert can analysis document for physical erasure by using different light arrangements like transmitted light, oblique light and illuminated stereoscopic microscope can also be used.

Chemical erasures on the other hand are those which utilize use of different chemicals to remove the original writing from the document. Rewriting is done on the erased portions of the document. Detection of chemical erasures can be done by using ultra violet florescence, infrared luminescence using instruments like video spectral comparator (VSC) and projectina.

7. Invisible ink writing:

Invisible ink is another tool used by the forgers to tamper the documents. A material or a solution that is used for the purpose of writing and is not visible to the naked eyes until treated by some developing reagent or by undergoing process of decipherment is called invisible ink, also referred to as secret ink, magic ink, or sympathetic ink and it is one form of stegnography. Some invisible inks are temperature dependent and some may depends on acid -base reactions like ammonia fumes are used to develop phenolphthalein or thymolphthalein inks. Some invisible inks can be viewed under U.V. light.

Invisible inks can be used to write something, which can be easily removed later and replace with another information of our interest. These types of alteration are very common among forgers these days. There are numbers of cases available in which invisible ink pens are used to commit the crime. With this objective our purpose is to atleast detect that any kind of alteration is done on a document. Sometimes it becomes difficult to restore the original writing even by applying various methods. In that case it would be beneficial if we can surely tell that some kind of alteration is done on a particular area of a document.

Forensic document examiner must be able to detect and identify the documents that were altered in order to change the information contained in that document. Alteration can be done in form like addition, erasure, insertion etc. Alteration can be done on any type of a document whether handwritten, typewritten, printed or photocopied. Document examiner need to be able to decipher the area of alteration in a document.

Different examination methods and techniques are available which can be used to detect various types of alteration done in different types of documents.

5.3 Methodology:

5.3.1 Material used:

1. Blue disappearing ink pen (Vikson International)
2. Blue, Black & Red erasable pen of 3 different brands: Pilot, Hamley Hamster & Uniball office solutions
3. Blue, Black & Red ink Pilot HiTecpoint V5 pen
4. Three variety of papers: White Copier paper (70gsm), Bond paper (90gsm) and Glossy paper (180gsm)
5. Video Spectral Comparator -8000

5.3.2 Sample Preparation:

Total 450 samples were collected, 50 samples for each type of paper and ink colour. 50 samples for blue ink on copier paper, 50 samples for black ink on copier paper and 50 samples for red ink on copier paper. Similarly samples were prepared for bond paper and glossy paper.

Samples were prepared by using erasable ink pen & disappearing ink pen on three different variety of papers i.e. copier paper, bond paper & glossy paper.

Pilot HiTecpoint V5 normal ink pens are used to prepare the samples. In this process few words were written with erasable ink pens and disappearing ink pen and then removed from the study paper. Normal ink pen is then used to overwrite over that area to alter the meaning of the message on the sample(document). All the samples are prepared in a similar way on all three varieties of paper and by using different pen brands.

Writings of erasable pen are removed by using pen erasure fitted at the tip of each pen.

All the samples were examined at CBI-CFSL, New Delhi.

Each line of all the samples is altered by different brand of invisible ink:

- First line is altered by using erasable Hamley Hamster pen
- Second line is altered by using erasable Pilot pen
- Third line is altered by using erasable Uniball pen
- Forth line is altered by using disappearing ink pen (only in case of blue ink)

The test samples were examined with U.V. light and Spot light of Video Spectral Comparator (VSC).

5.4 Observations and Results:

In this research we have used physical rubber erasures incorporated at the tip of each erasable ink pen to remove the ink lines of erasable pen. Alterations are done by first removing the erasable ink pen writing and then rewrite something else at that place with normal ink pen.

Three brands of erasable ink pen are used and one disappearing ink pen is used to prepare samples. Erasable ink pen of three colours i.e. blue, black and red is used.

5.4.1 Results of Blue ink samples:

Table 5.1: Results of obliterated writing examination of Blue invisible ink by using VSC

BLUE INK													
S. No.		Hamley Hamster			Pilot			Uniball			Disappearing ink		
	Wave-length	Copier	Bond	Glossy	Copier	Bond	Glossy	Copier	Bond	Glossy	Copier	Bond	Glossy
	U.V. – Visible Light												
1	365nm	NV	PV	NV	V	PV	PV	PV	PV	PV	NV	NV	PV
2	312nm	PV	PV	PV	V	V	PV	V	V	PV	V	V	PV
3	254nm	V	V	V	V	V	V	V	V	V	V	V	V
	SPOT Light												
4	645nm	V	V	V	V	V	V	V	V	V	PV	PV	PV
5	665nm	V	V	V	V	V	V	V	V	V	PV	PV	NV
6	695nm	PV	PV	PV	PV	PV	PV	PV	PV	PV	PV	PV	NV
7	715nm	PV	PV	PV	PV	PV	PV	PV	PV	PV	NV	NV	NV
8	725nm	NV	NV	NV	NV	NV	NV	NV	NV	NV	NV	NV	NV
9	780nm	NV	NV	NV	NV	NV	NV	NV	NV	NV	NV	NV	NV
10	830nm	NV	NV	NV	NV	NV	NV	NV	NV	NV	NV	NV	NV

V - **Visible**
PV - **Partially Visible**
NV - **Not Visible**
SM - **Smudging Visible**

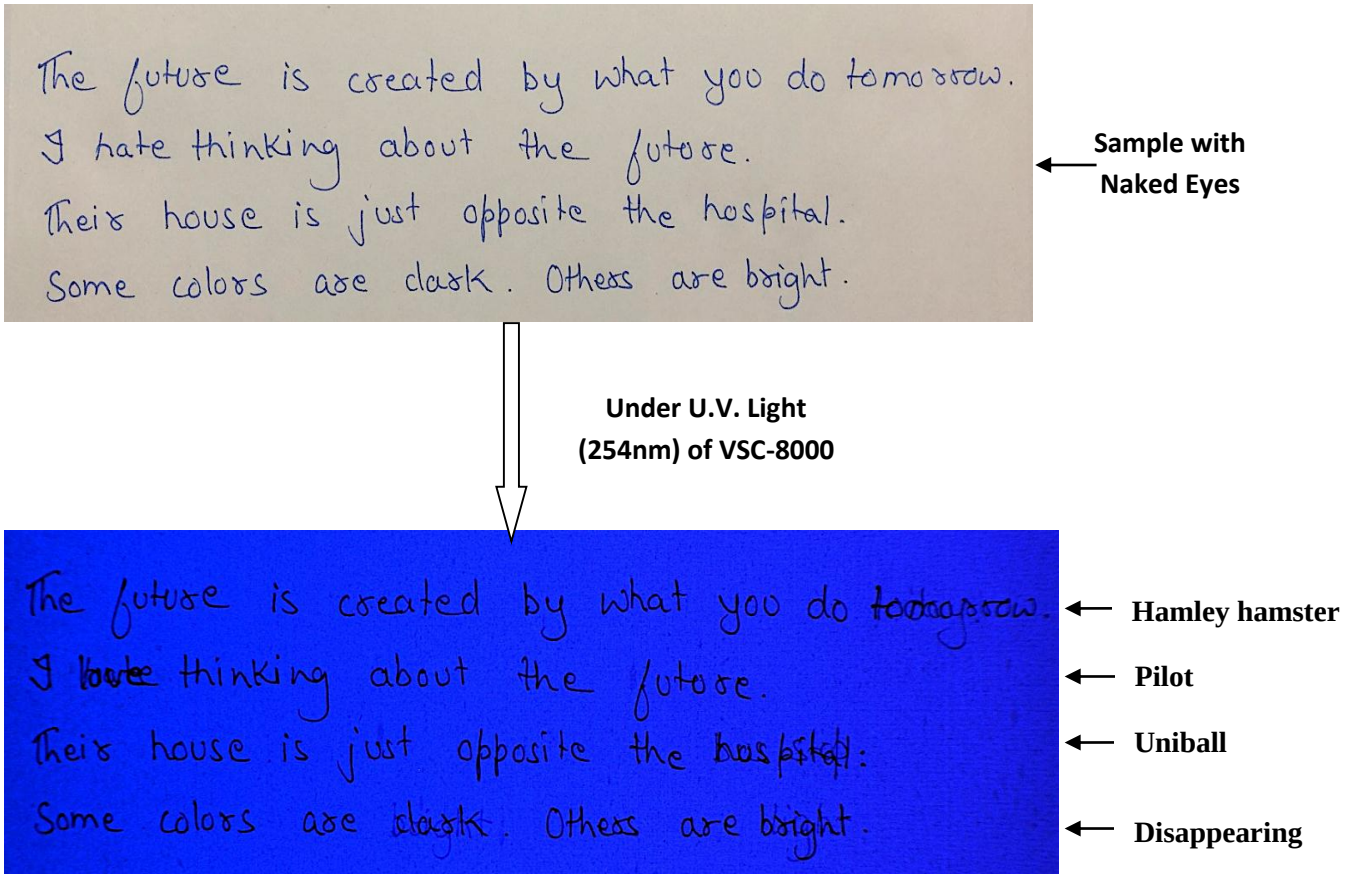


Figure 5.1: Erasable & disappearing blue ink writings on copier paper visible under the U.V. light of VSC-8000

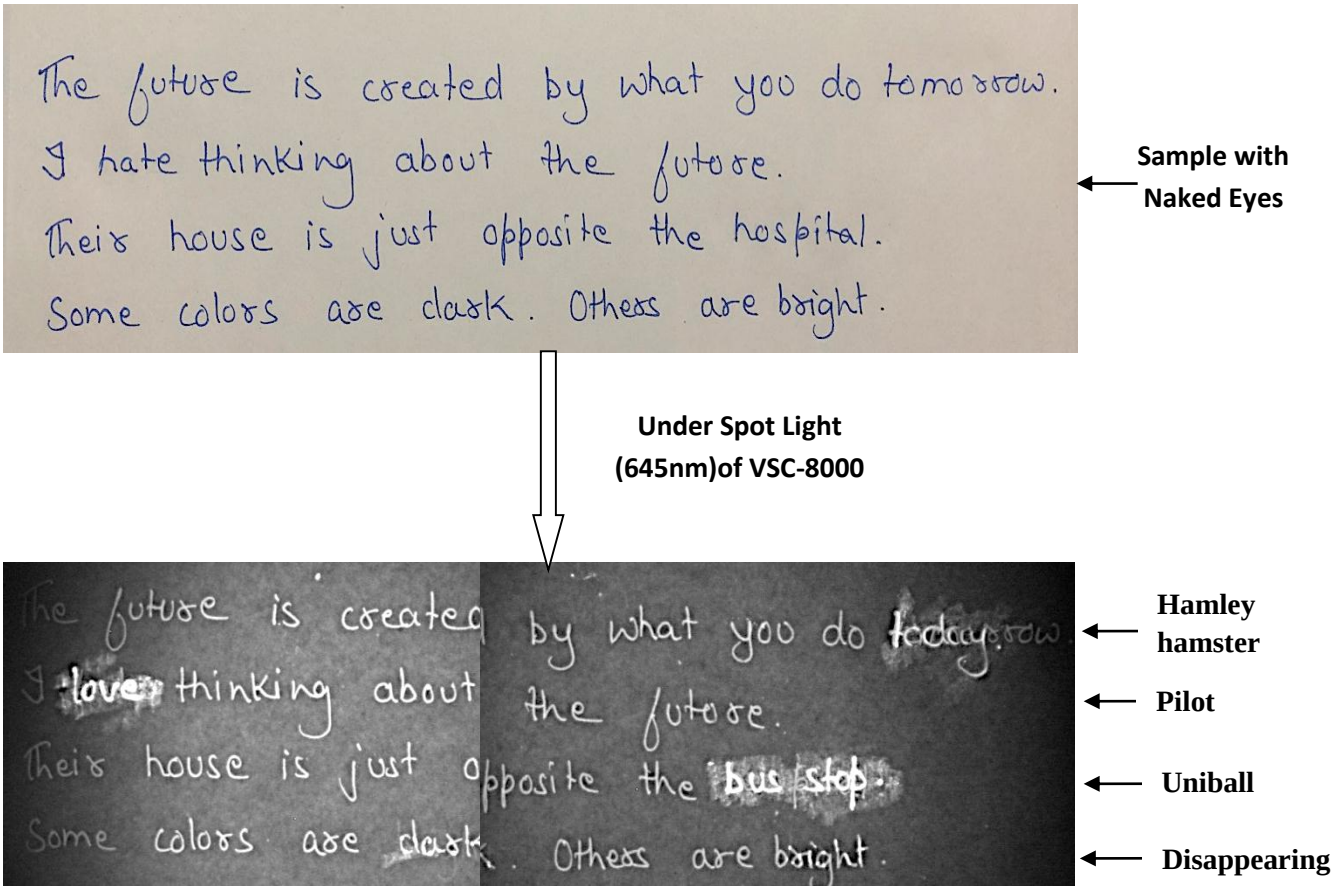


Figure 5.2: Erasable & disappearing blue ink writings on copier paper visible under the spot light of VSC-8000

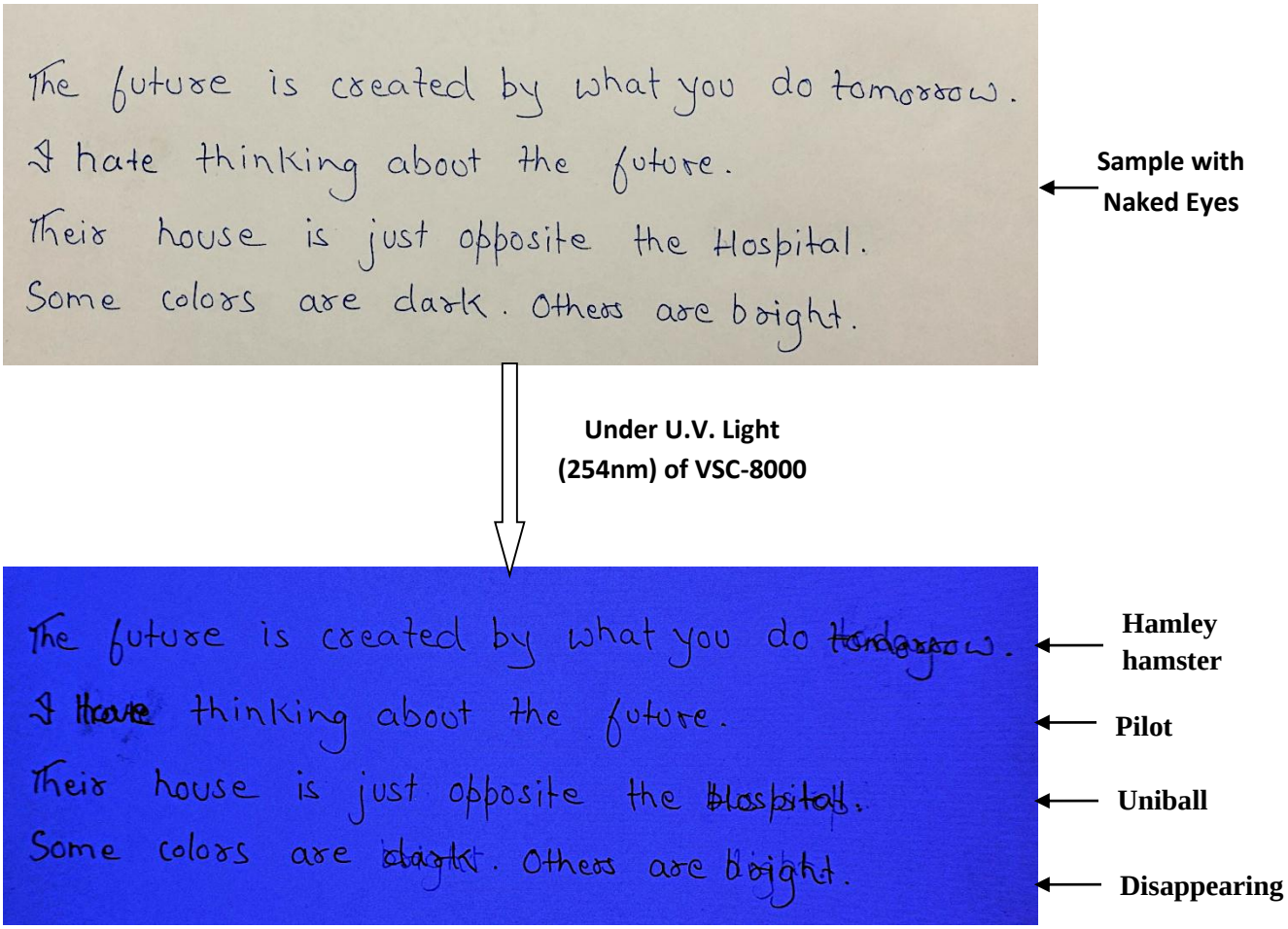


Figure 5.3: Erasable & disappearing blue ink writing on bond paper visible under the U.V. Light of VSC-8000

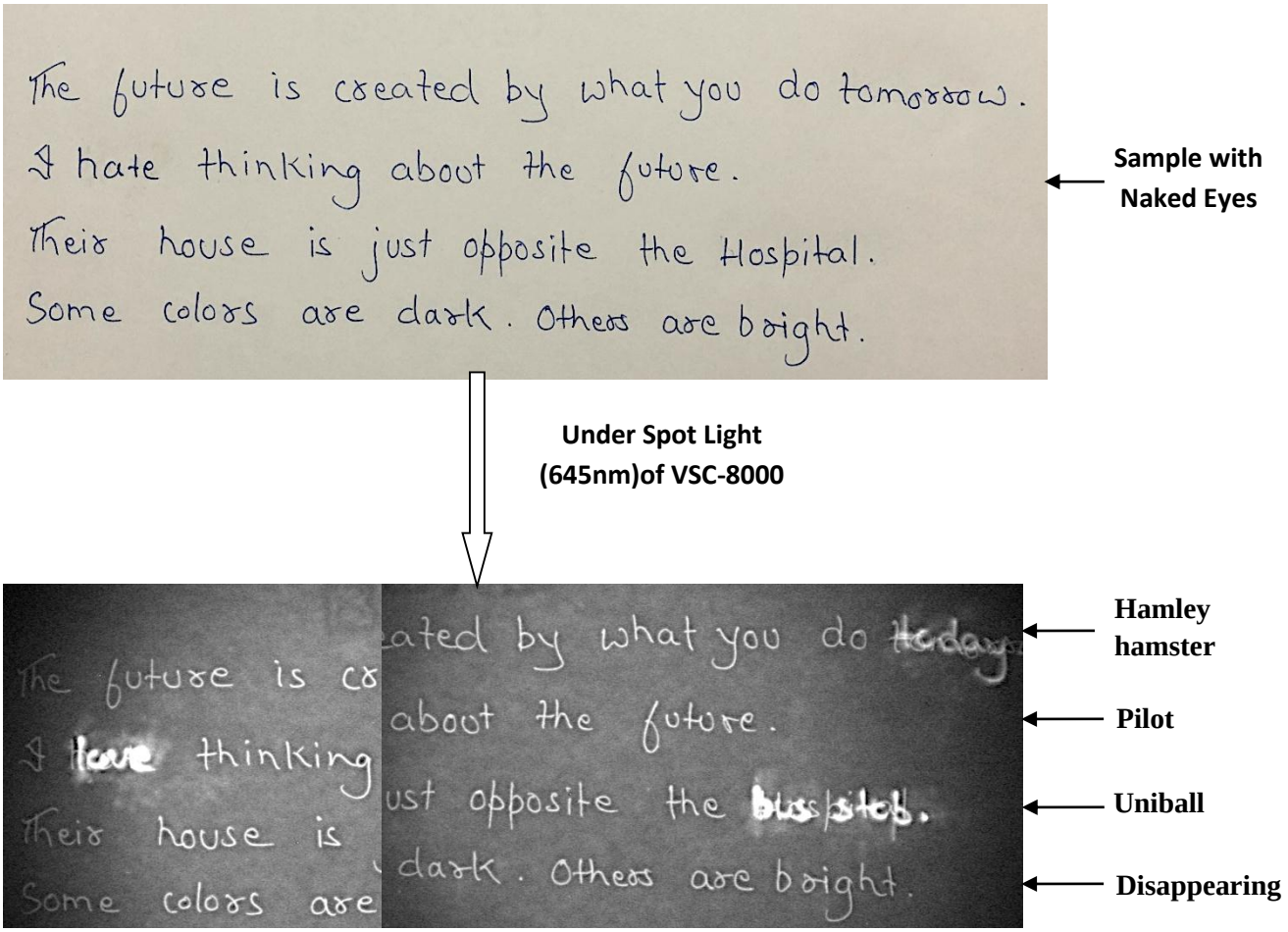


Figure 5.4: Erasable & disappearing blue ink writing on bond paper visible under the spot light of VSC-8000

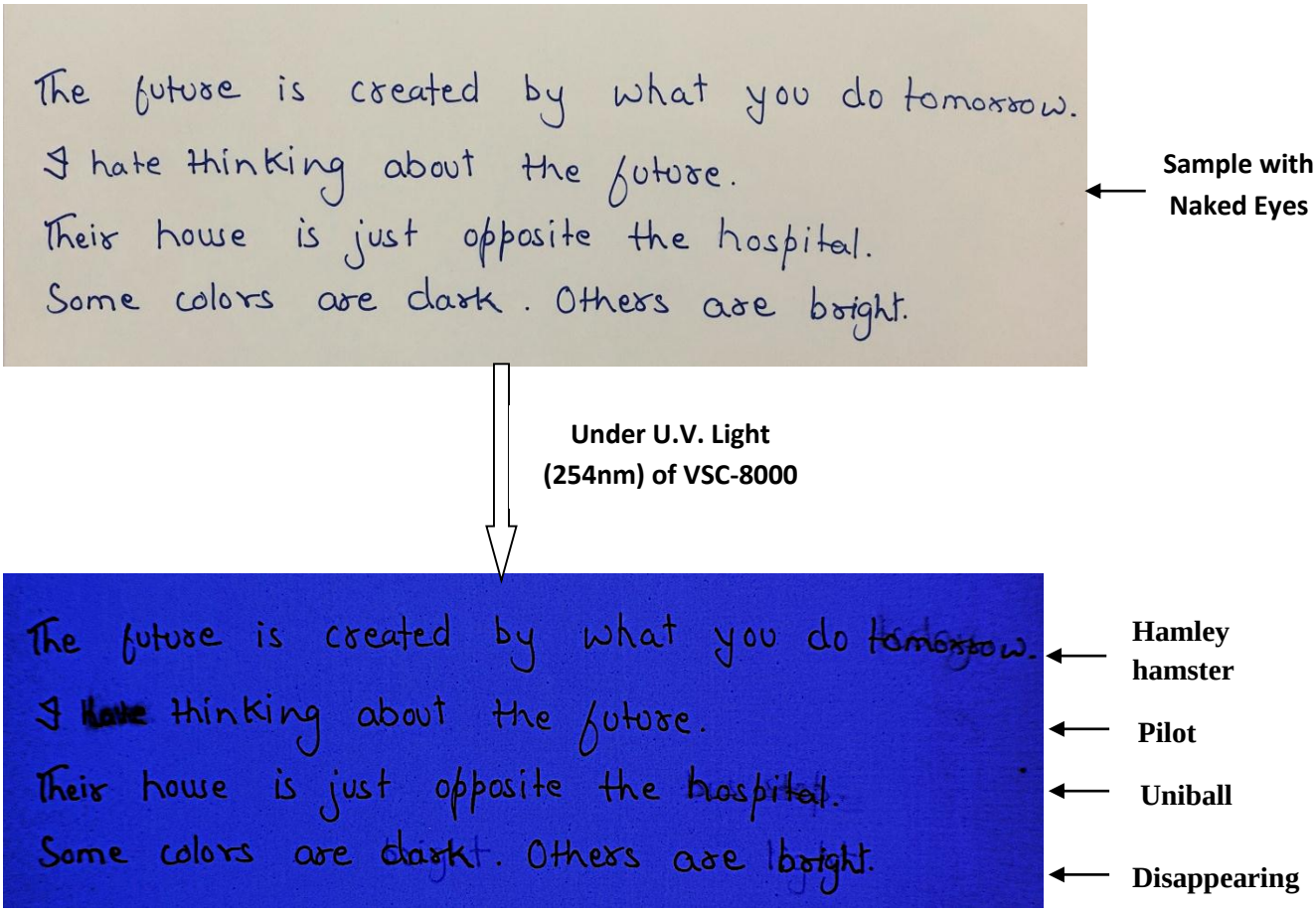


Figure 5.5: Erasable & disappearing blue ink writing on glossy paper visible under the U.V. light of VSC-8000

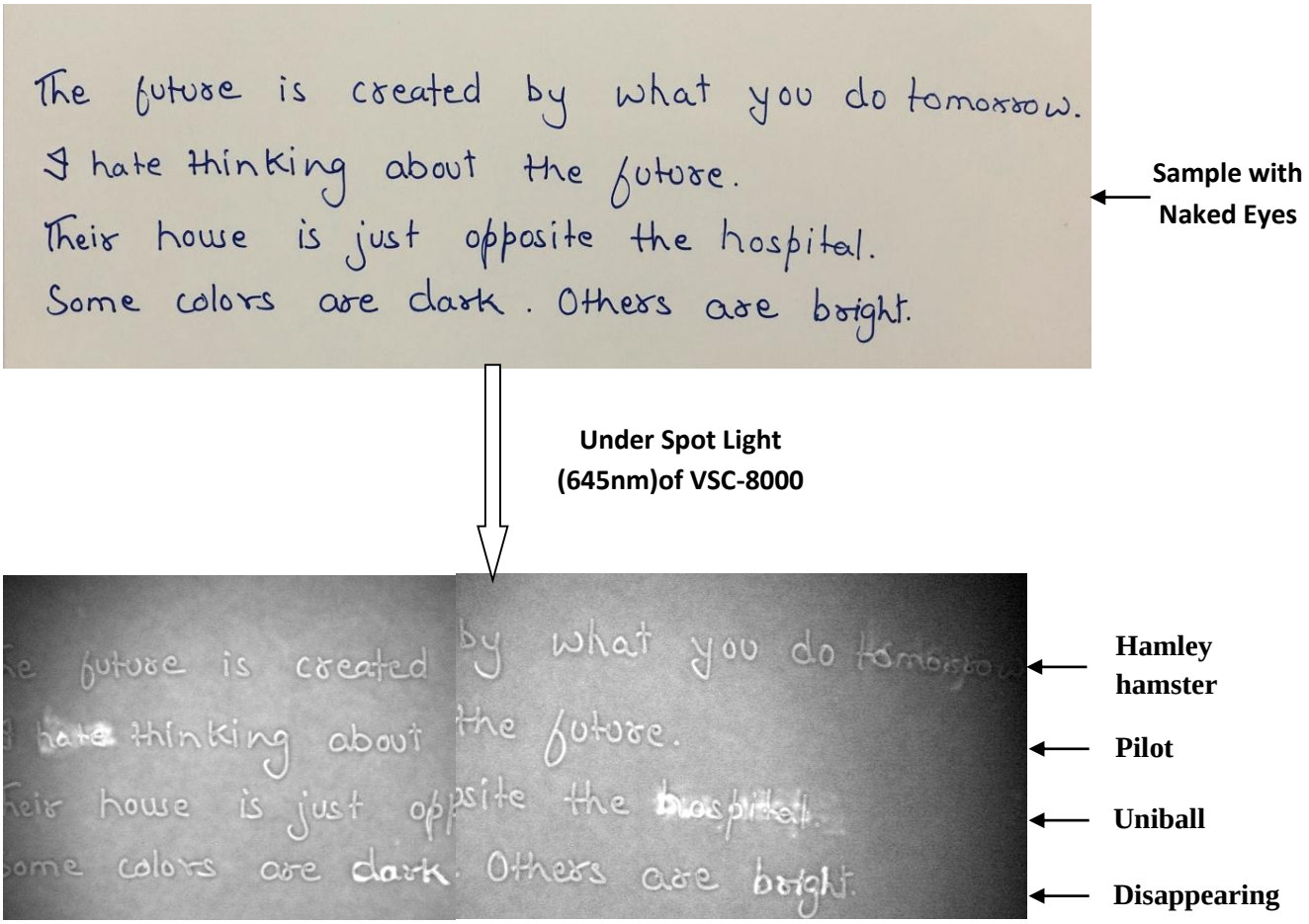


Figure 5.6: Erasable & disappearing blue ink writing on glossy paper visible under the spot light of VSC-8000

It was found that when U.V. light of VSC is used than all the writing or alterations become visible at 254nm. In some of the cases smudging effect was also found. When analysed with Spot light of VSC most of the writings become visible at 645nm. Disappearing ink on copier paper and bond paper is not able to become completely visible but traces are visible through which one can tell that some alteration is done at that place. Smudging effect is less in case of blue ink.

5.4.2 Results of Black in samples:

Table 5.2: Results of obliterated writing examination of Black invisible ink by using VSC

BLACK INK										
S.No.		Hamley Hamster			Pilot			Uniball		
	Wavelength	Copier	Bond	Glossy	Copier	Bond	Glossy	Copier	Bond	Glossy
	U.V. – Visible Light									
1	365nm	NV	NV	PV	V	V	V	PV	PV	PV
2	312nm	V	V	V	V	V	V	V	V	V
3	254nm	V	V	V	V	V	V	V	V	V
	SPOT Light									
4	645nm	V	V	V	V	V	V	V	V	V
5	665nm	V	V	V	V	V	V	V	V	V
6	695nm	PV	PV	PV	PV	PV	PV	PV	PV	PV
7	715nm	PV	PV	PV	PV	PV	PV	PV	PV	PV
8	725nm	NV	NV	NV	NV	NV	NV	NV	NV	NV
9	780nm	NV	NV	NV	NV	NV	NV	NV	NV	NV
10	830nm	NV	NV	NV	NV	NV	NV	NV	NV	NV

V - **Visible**
PV - **Partially Visible**
NV - **Not Visible**
SM - **Smudging Visible**

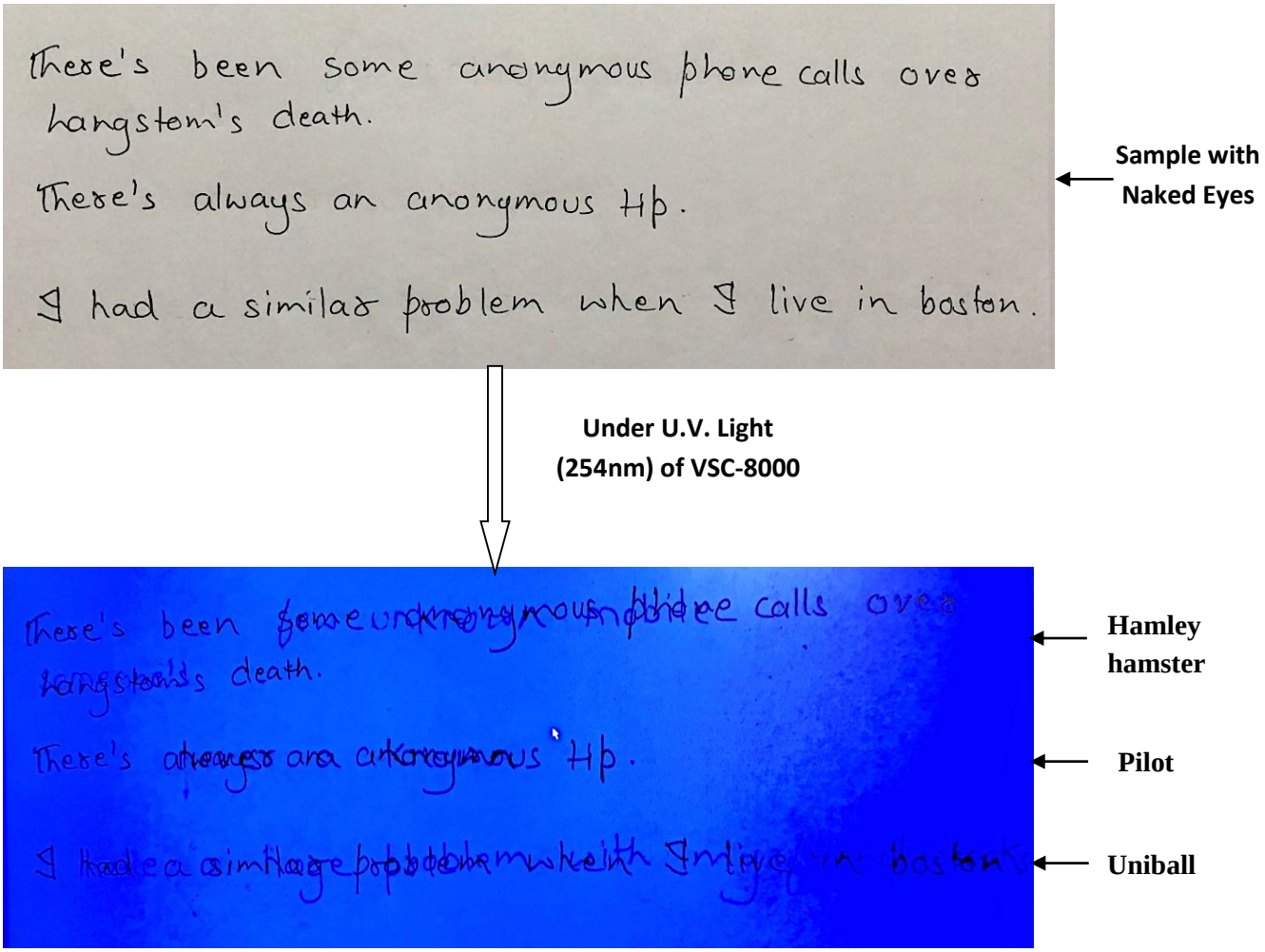


Figure 5.7: Erasable black ink writing on copier paper visible under the U.V. light of VSC-8000

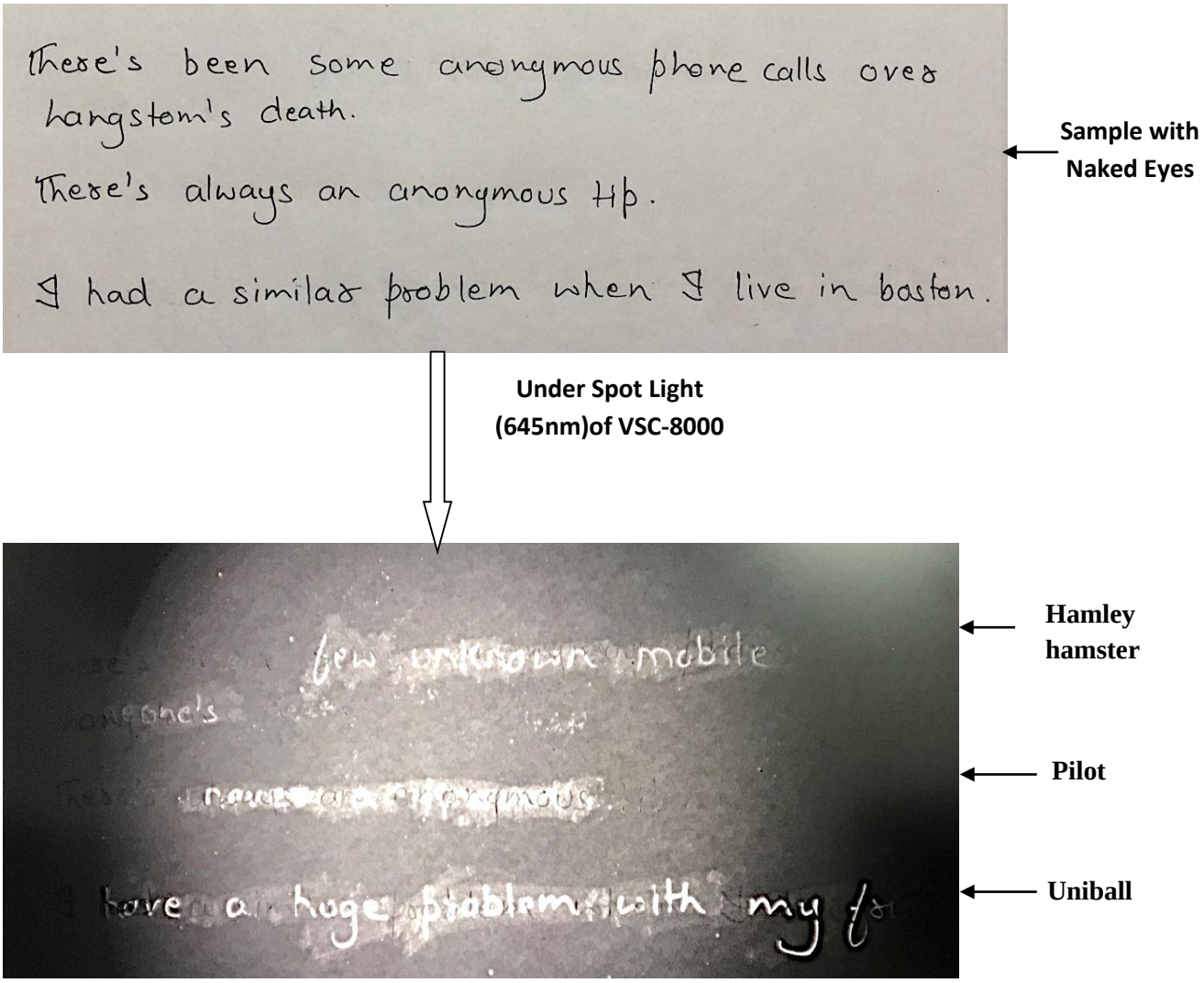


Figure 5.8: Erasable black ink writing on copier paper visible under the spot light of VSC-8000

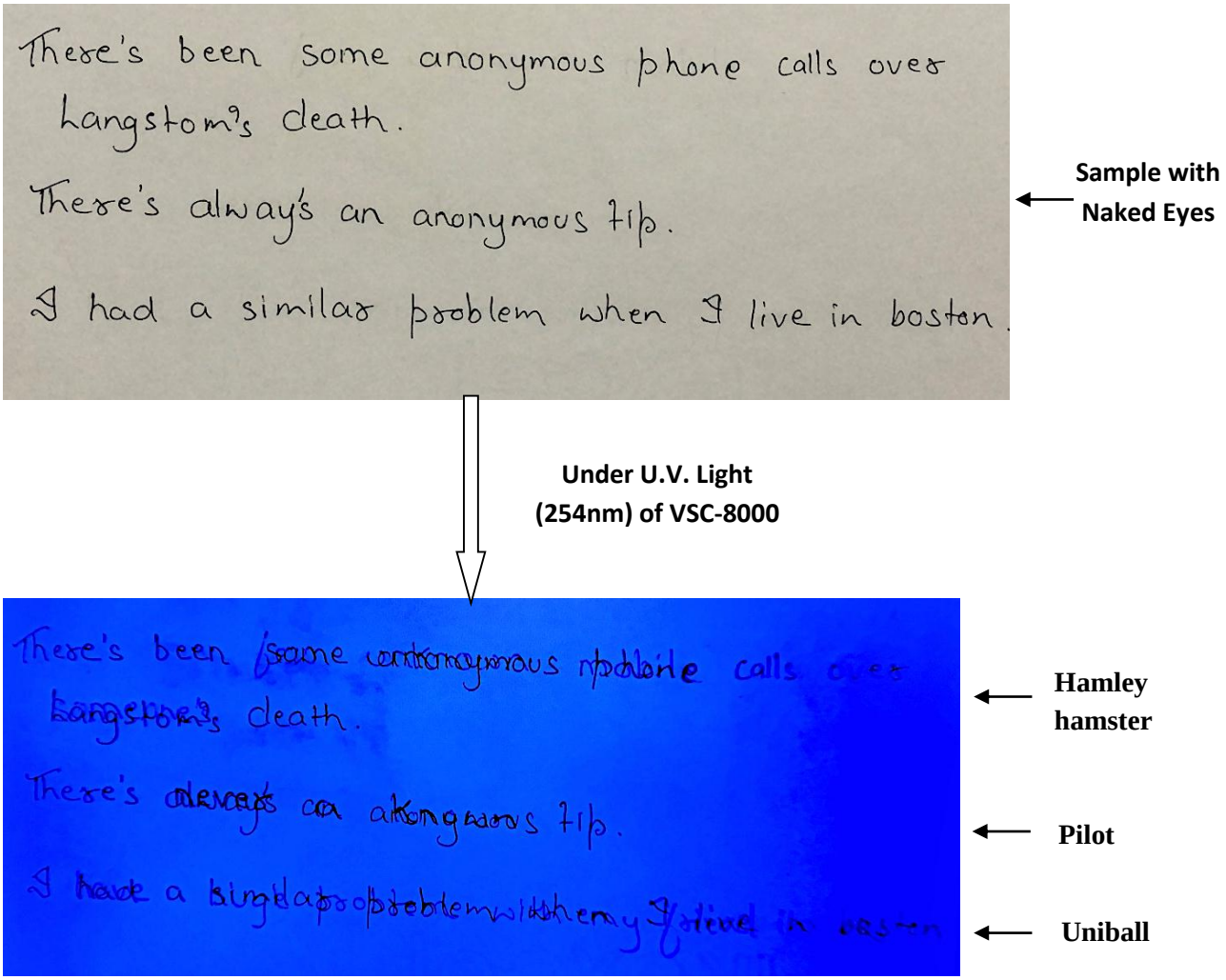


Figure 5.9: Erasable black ink writing on bond paper visible under the U.V. light of VSC-8000

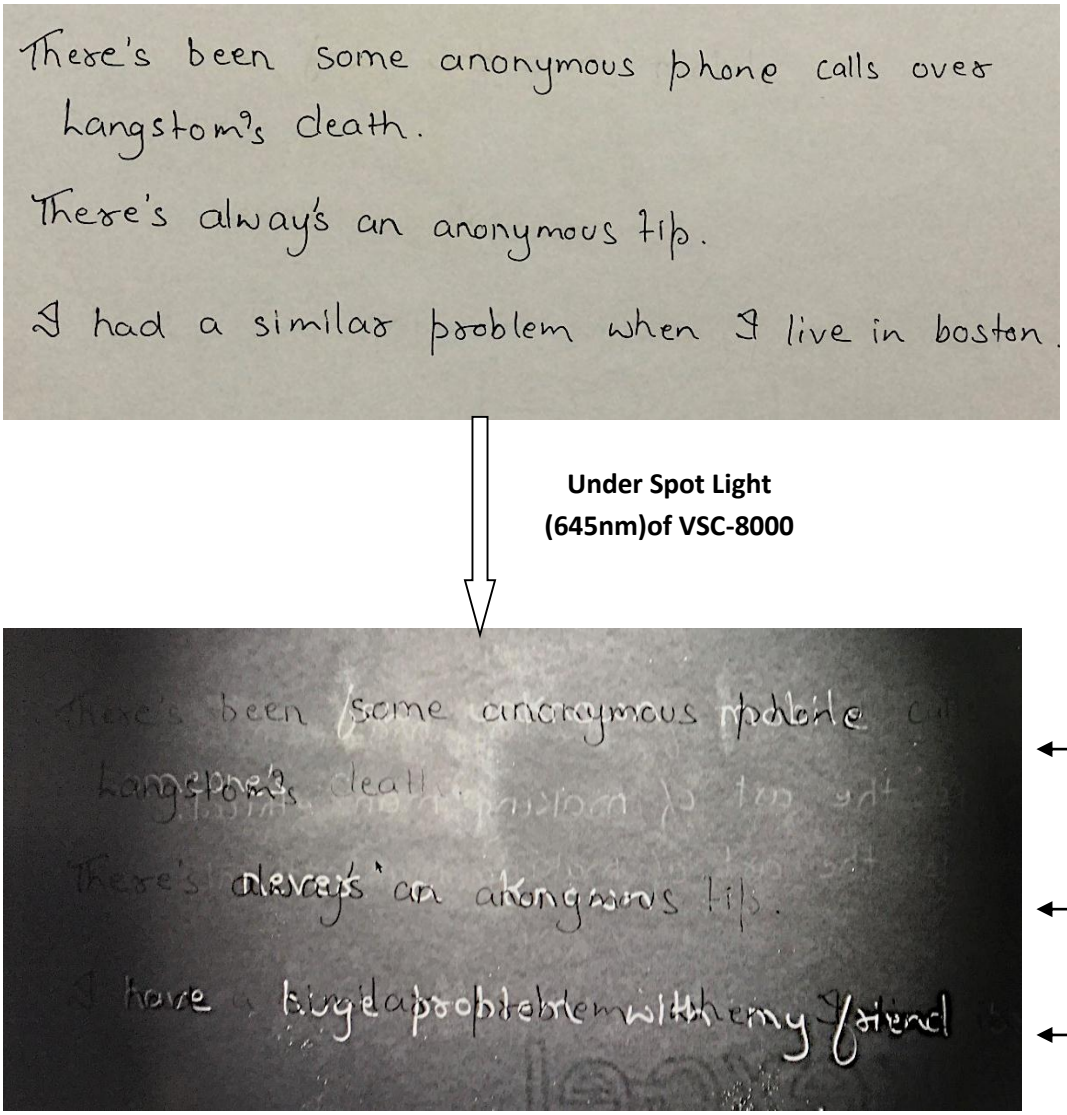


Figure 5.10: Erasable black ink writing on bond paper visible under the spot light of VSC-8000

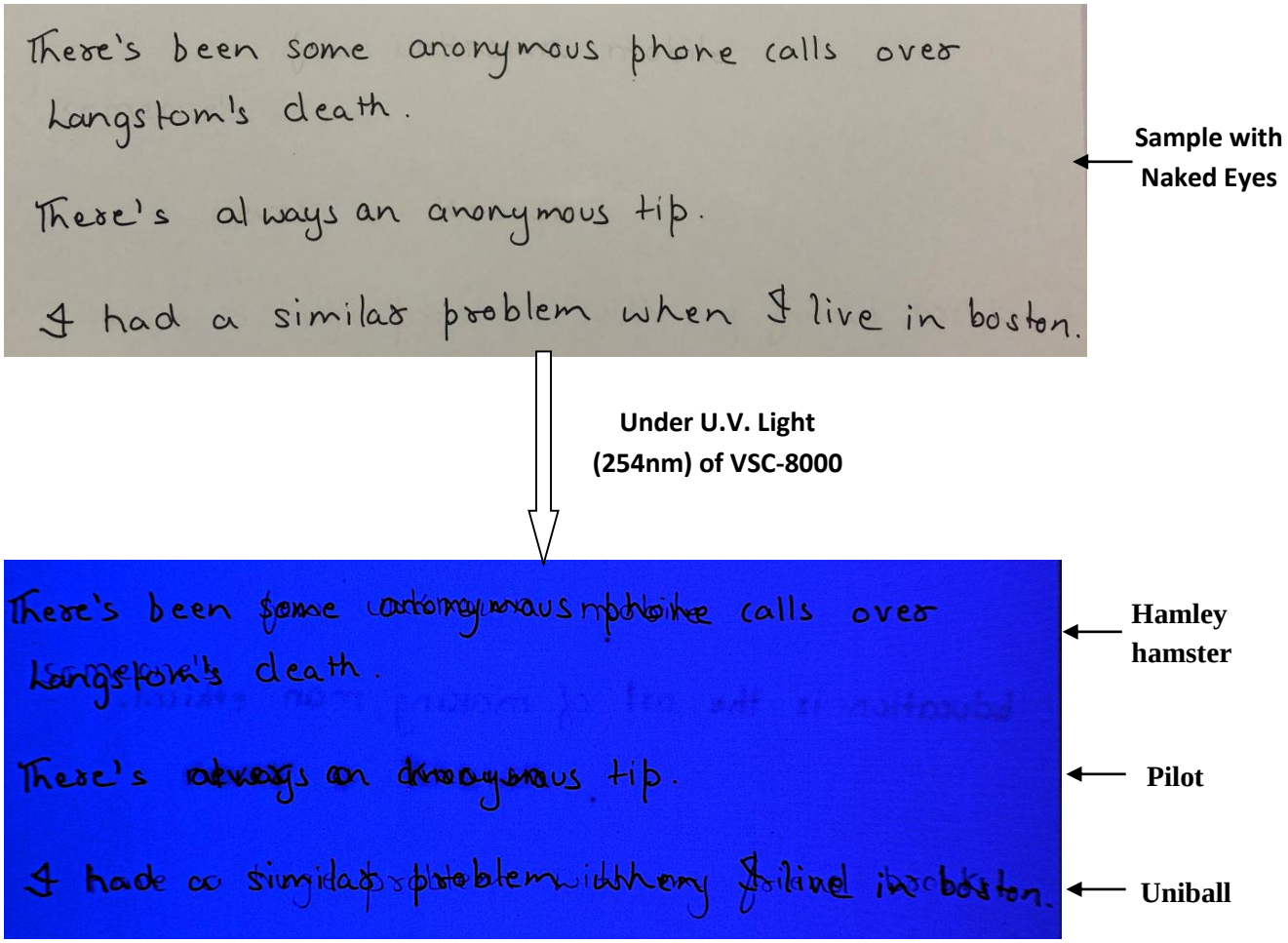


Figure 5.11: Erasable black ink writing on glossy paper visible under the U.V. light of VSC-8000

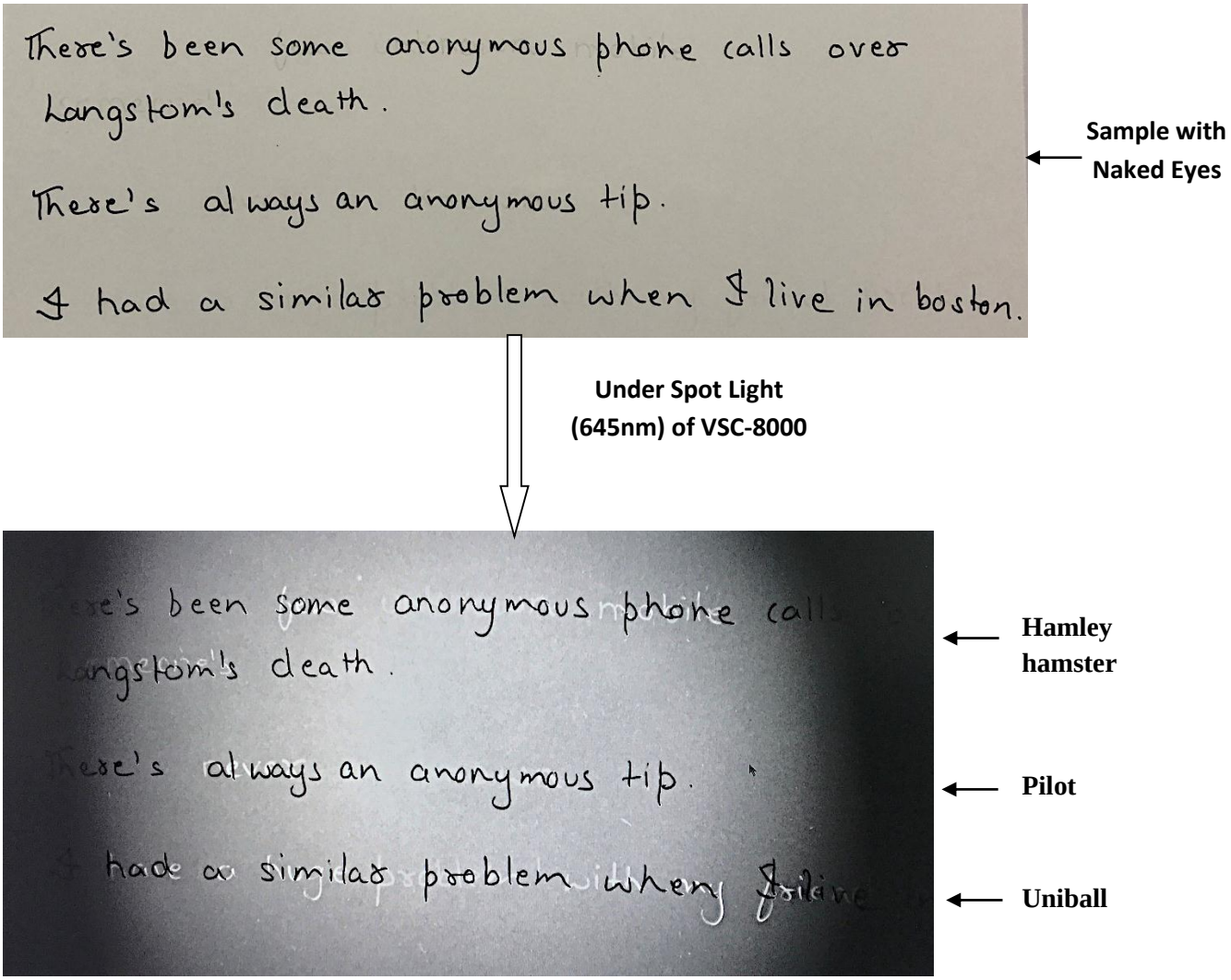


Figure 5.12: Erasable black ink writing on glossy paper visible under the spot light of VSC-8000

It was found that when U.V. light of VSC is used than all the writing or alterations become clearly visible at 254nm. When analysed with Spot light of VSC most of the writings become visible at 645nm. Smuding was more in case of copier paper. The writing starts to fade away after 715nm.

5.4.3 Results of Red ink samples:

Table 5.3: Results of obliterated writing examination of Red invisible ink by using VSC

RED INK										
S.No.		**Hamley Hamster**			**Pilot**			**Uniball**		
	Wavelength	**Copier**	**Bond**	**Glossy**	**Copier**	**Bond**	**Glossy**	**Copier**	**Bond**	**Glossy**
	U.V. – Visible Light									
1	365nm	NV	NV	PV	V	V	PV	PV	PV	PV
2	312nm	PV	PV	PV	V	V	SV	V	V	PV
3	254nm	V	V	SV	V	V	SV	V	V	SV
	SPOT Light									
4	645nm	SV	V	SV	SV	V	SV	SV	V	SV
5	665nm	SV	SV	V	SV	SV	SV	SV	SV	SV
6	695nm	SV	SV	SV	SV	SV	SV	SV	SV	SV
7	715nm	SV	SV	SV	SV	SV	SV	SV	SV	SV
8	725nm	SV	SV	SV	SV	SV	SV	SV	SV	SV
9	780nm	NV	NV	NV	NV	NV	NV	NV	NV	NV
10	830nm	NV	NV	NV	NV	NV	NV	NV	NV	NV

V - **Visible**
PV - **Partially Visible**
NV - **Not Visible**
SM - **Smudging Visible**

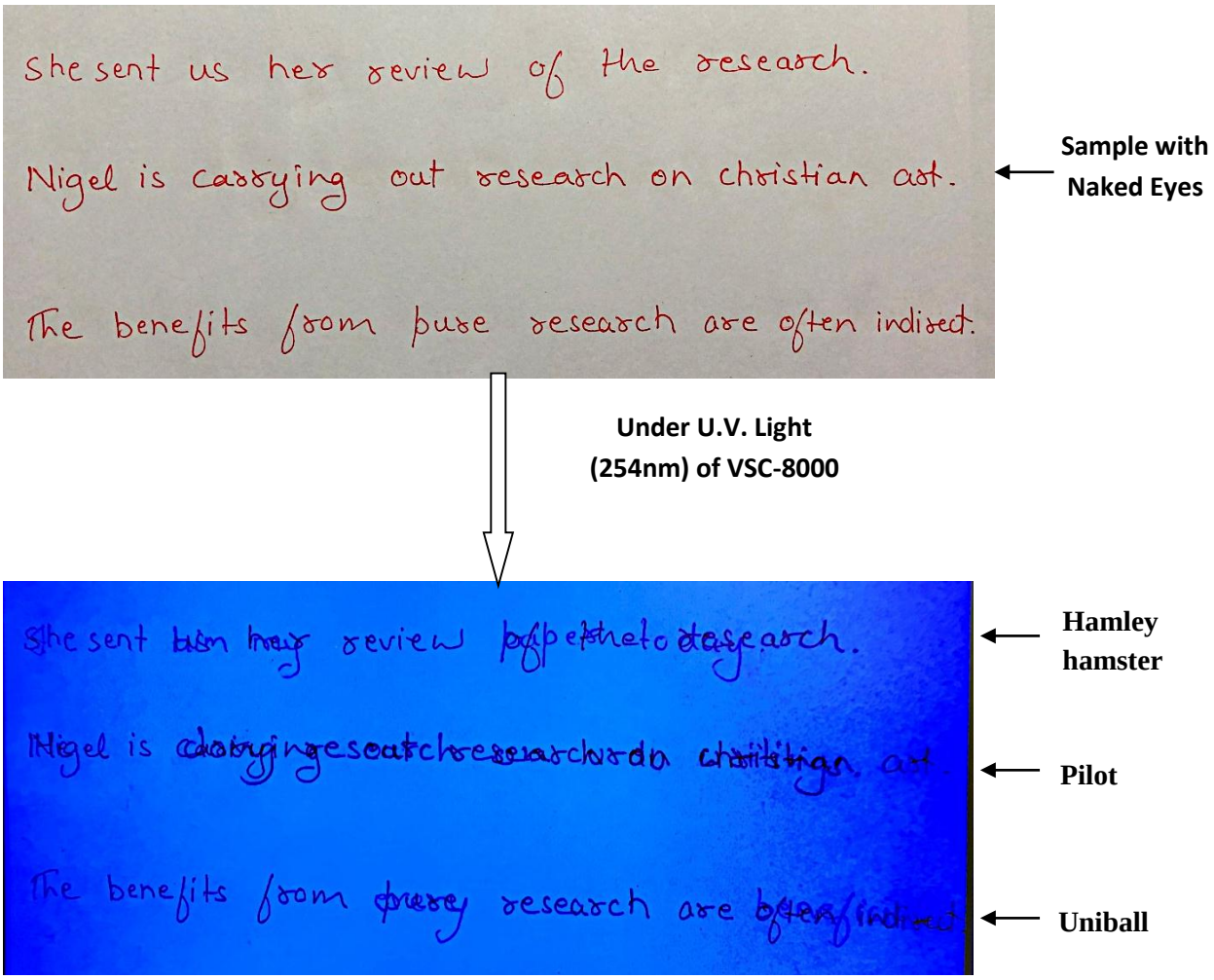


Figure 5.13: Erasable red ink writing on copier paper visible under the U.V. light of VSC-8000

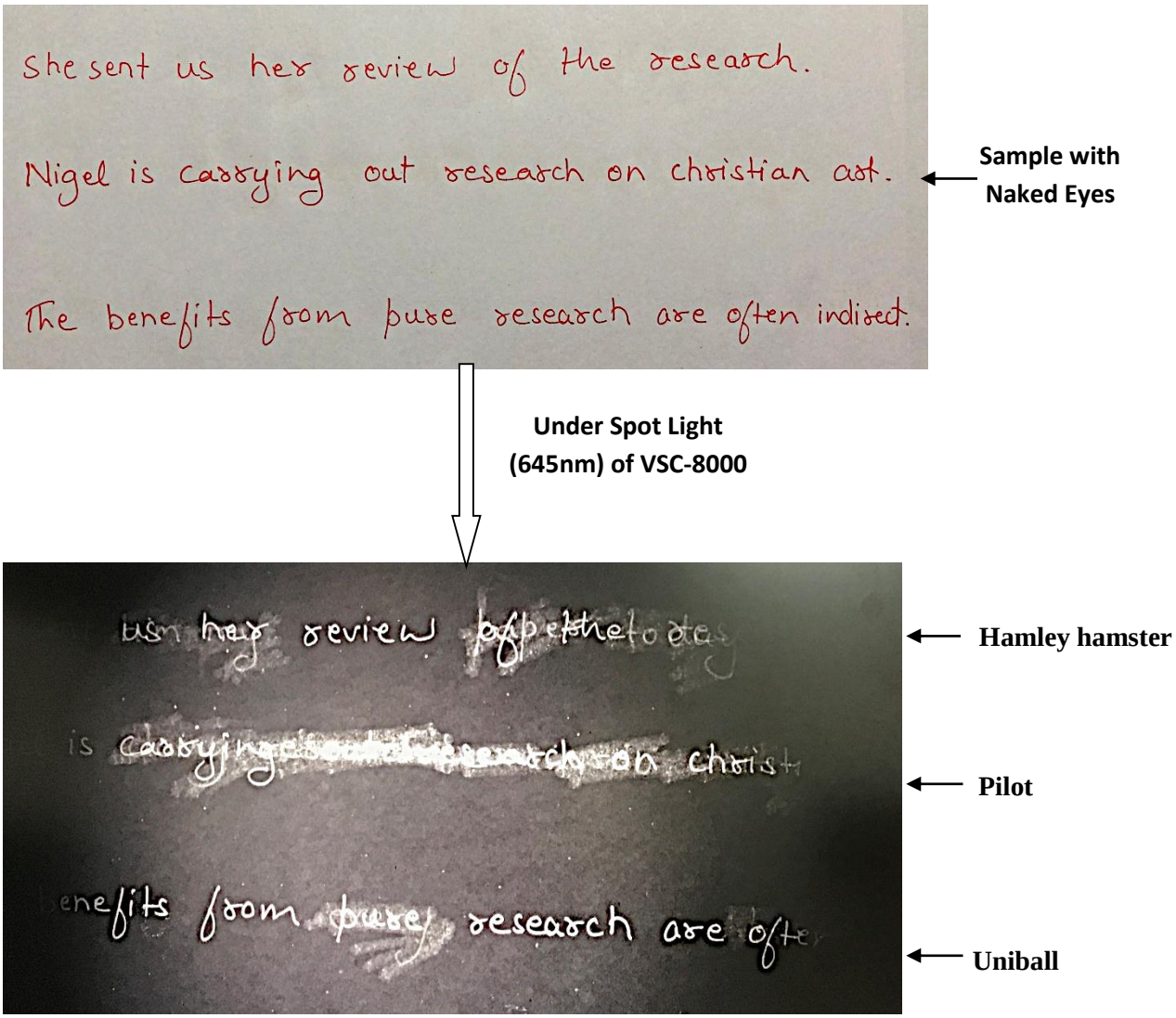


Figure 5.14: Erasable red ink writing on copier paper visible under the spot light of VSC-8000

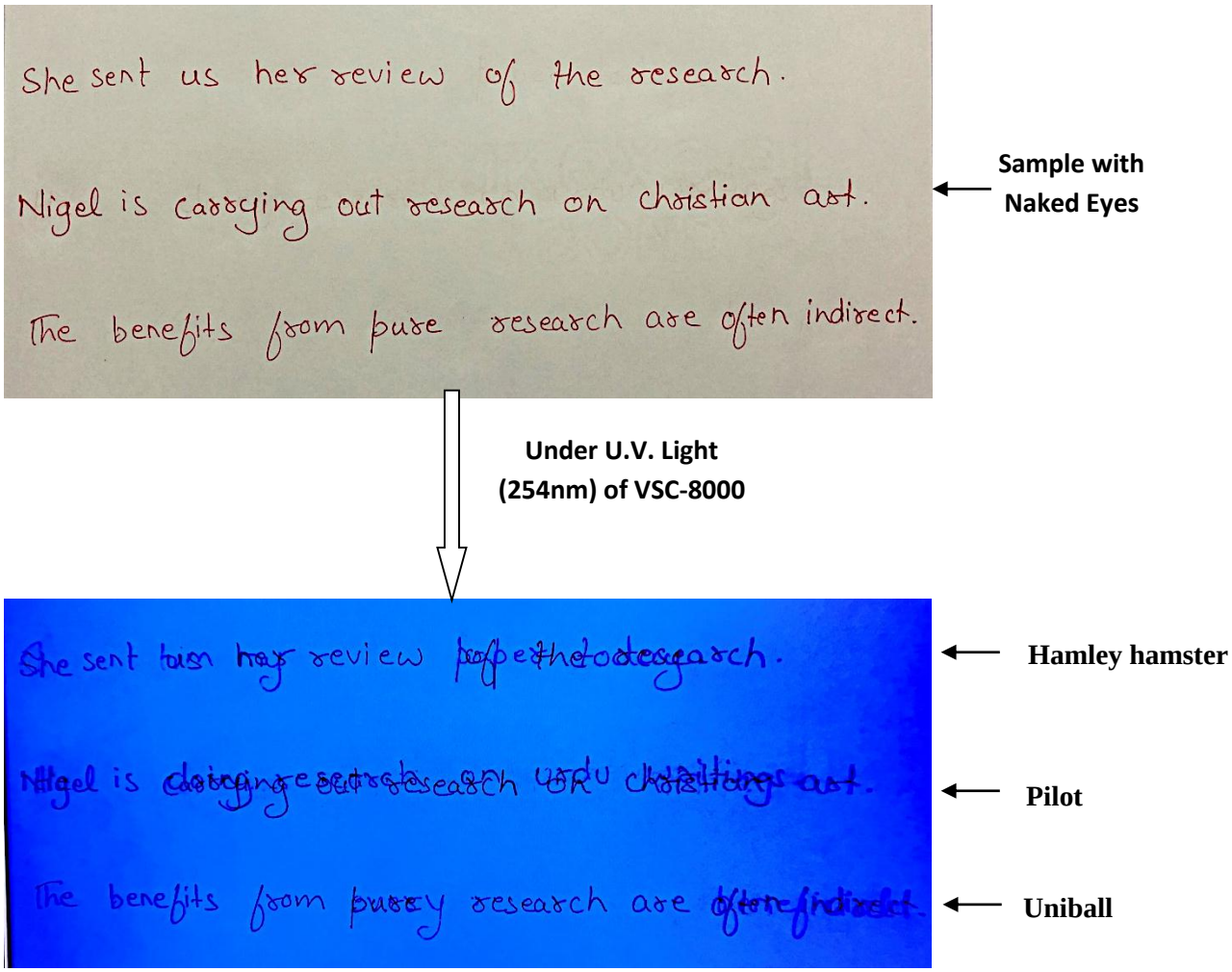


Figure 5.15: Erasable red ink writing on bond paper visible under the U.V. light of VSC-8000

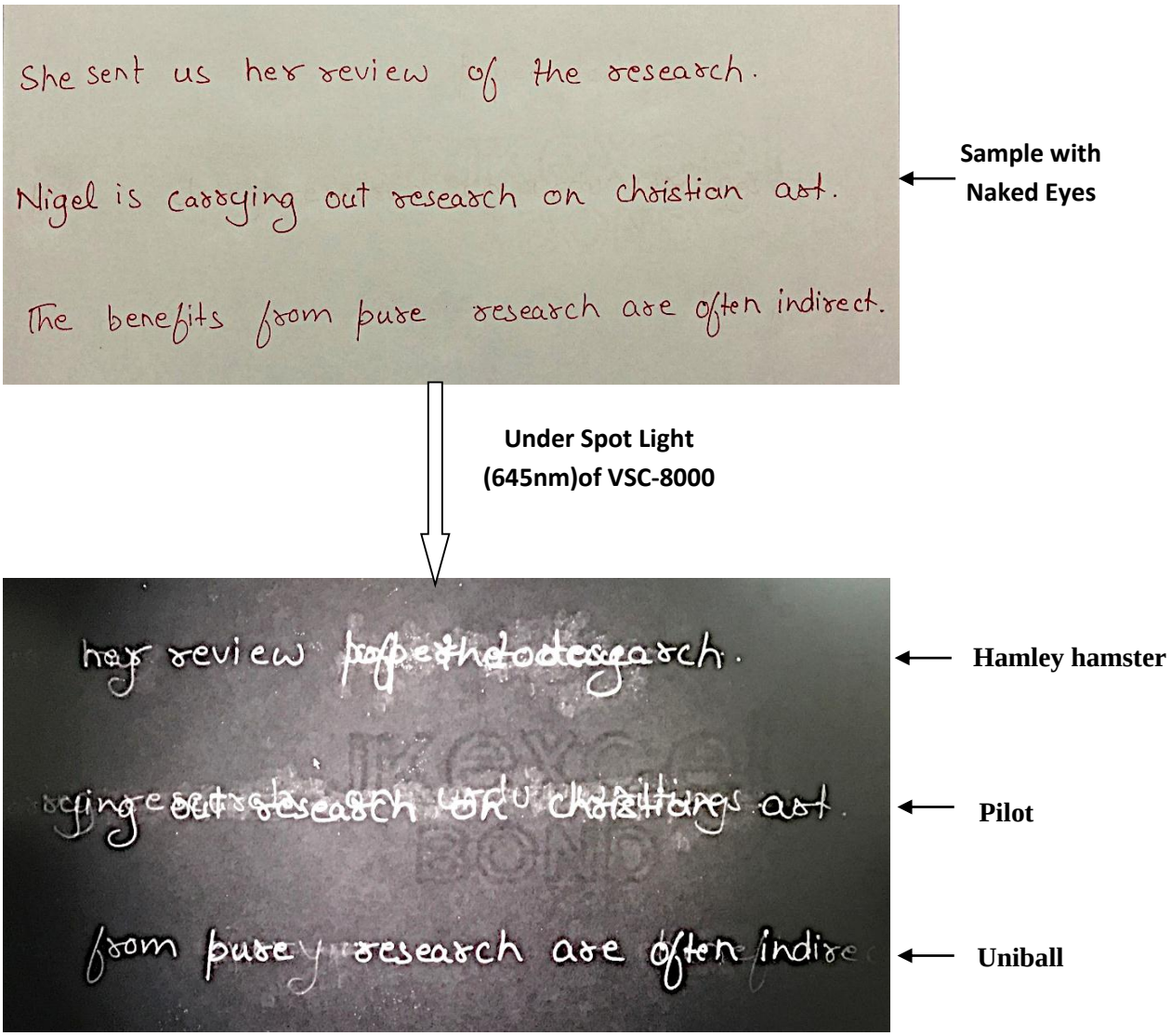


Figure 5.16: Erasable red ink writing on bond paper visible under the spot light of VSC-8000

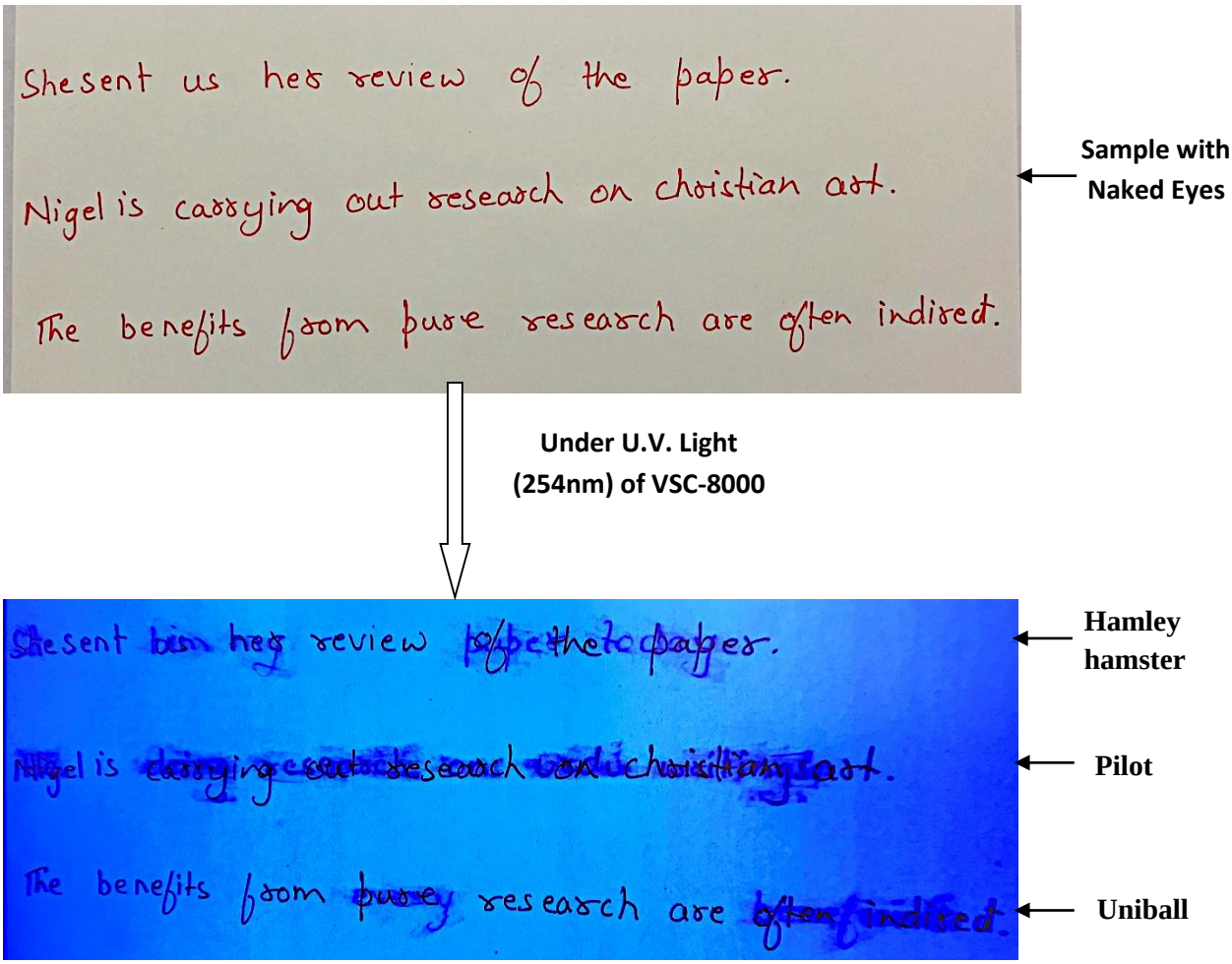


Figure 5.17: Erasable red ink writing on glossy paper visible under the U.V. light of VSC-8000

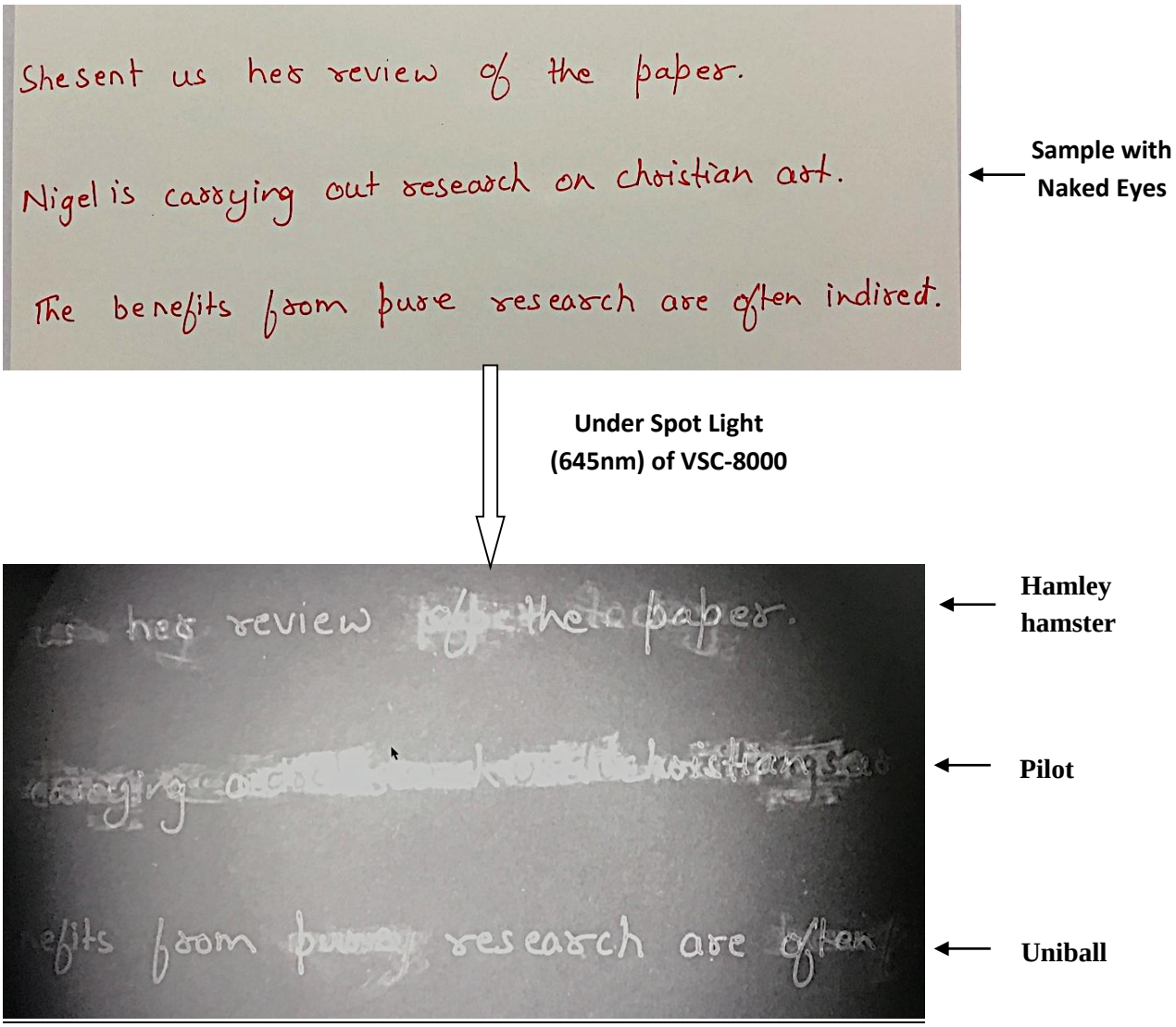


Figure 5.18: Erasable red ink writing on glossy paper visible under the spot light of VSC-8000

It was found that when U.V. light of VSC is used than all the writing or alterations become clearly visible at 254nm. When analysed with Spot light of VSC the writings of red ink are not visible in readable form, instead they are smudged even on copier paper. Smudging is more on copier paper and glossy paper. This smudging effect is the result of rubber erasure that is used to remove the erasable ink writing. Although one cannot read what is written but signs of alteration are clearly visible through which one can surely tell that some alterations are done on that particular place which can help the investigating officer in further investigation.

5.5 Conclusion:

Video spectral comparator (VSC) is a versatile instrument that can be used to analyse questioned documents in various cases. It can also be utilize to decipher invisible ink writings. In the present research we used VSC- 8000 to decipher the overwriting alterations done by using invisible ink on copier paper, bond paper and glossy paper. It was found that alterations on all mentioned types of paper can be detected by analysing the sample under the U.V. light and Spot light of VSC. In some cases erased writings are not clearly readable due to the smudging of the ink caused by friction rubber eraser used to remove the ink lines. Even though we cannot restore all the writing in readable form but smudged areas visible surely tells us that some alterations are done at that place. This can help the examiner for further analysis.

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ORIGINAL RESEARCH PAPER

VISUALIZATION OF THERMOCHROMIC INK & DISAPPEARING INK WRITINGS THROUGH VARIOUS TECHNIQUES ON DIFFERENT PAPER SURFACES

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Abstract

Invisible ink are becoming a popular tool for committing various economical and financial frauds. Temperature dependent erasable ink and pH indicator disappearing ink both are widely used for this purpose. In this research paper we have explained different techniques to decipher these invisible writings. Examination through Photoshop software and U.V. Cabinet are very cost-effective, non destructive and easily available technique to decipher these writings. Chemical examination through iodine fuming, NaOH or KOH are also very effective and reliable method but they are destructive in nature. Visualization of invisible writing is best done by viewing the samples under the spot light and U.V. light available in Video Spectral Comparator -8000.

Keywords: Ink analysis, disappearing ink, questioned document, forensic science, invisible ink, erasable ink.

Introduction

Ink is a liquid that contain pigments or dyes and is used to color a surface to produce an image, text, or design with the help of pen or brush.

Invisible inks are also known as magic ink or sympathetic inks. It is a solution used for writing, which can be erased or become invisible after few minutes. A new technique of committing forgeries using these magic pens have increased the number of white collar crimes dramatically. So it becomes important to formulate a practicle, easy and a cost effective method to decipher such writings. Invisible inks are easily available in the local market which raise great deal of concern[4,14,15]. The main two varieties of invisible inks are disappearing ink and thermal ink.

Erasable ink are used as a tool to forge various types of documents. It can be removed easily by the rubber incorporated at the tip of the pen. For an erasable ink, The writing strokes of an erasable ink are manually manipulated with the help of the incorporated erasure[9-13]. It is available in different colours likes red, blue, green and black. Erasable inks is a type of ink that depends on the temperature of the ink solvent generated during erasure[22]. This ink starts fading when the temperature increases either manually by friction or by other direct sources[4-5].

These temperature dependent inks are becoming popular among criminals and are used for committing various types of crimes[11,12]. These Paper Mate manufactured erasable ink pens are sold under the name of "Replay" in UK. But now the brand of these erasable pen in UK had changed from Replay to "Erase Max". Pilot is manufacturing a large collection of erasable ink pens under the name "Frixion" erasable roller pen[3,6].

Leuco dye developer solvent system is the one used in thermochromic/thermal erasable inks. It is encapsulated in a polymer shield[2]. Colour change from coloured to colourless or vice-versa take place due to the interaction of three components i.e. leuco dye which is a colour former, developer and a solvent[7,16]. Colour former may be a spirolactone molecule. CVL (Crystal Violet Lactone) can be used as colour former, it is colourless in grounded form. Phenols are commonly used as developers in these ink. Most commonly used solvents in the preparation of disappearing ink are alcohol, amides, esters and acids having long chain aliphatic character[2,8].

Disappearing ink works on the basic principle of acid-base chemistry. It is made from a mixture of chemicals and it remain visible to the naked eye only for a short period of time depending upon the writing surface[17-18]. Most common pH indicator to make these inks is

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Thymolphthalein ($C_{28}H_{30}O_4$) is used for the preparation of blue colored ink at the pH 9.3-10.5 and Phenolphthalein $C_{20}H_{16}O_4$ (colorless to red at pH 8.2 - 9.8). Disappearing ink is basically a mixture of pH indicator like thymolphthalein or phenolphthalein, base like sodium hydroxide solution, ethyl alcohol and distilled water at pH-11. Increasing the temperature of sodium hydroxide leads to increased stability of the ink[3].

The water present in the ink reacts with carbon dioxide in the air to form carbonic acid. The carbonic acid then reacts with the sodium hydroxide in a neutralization reaction to form sodium carbonate. Due to this neutralization of the base, pH changes from basic to acidic and makes the indicator colourless, hence ink gets disappeared[3,14,15]:

Carbon dioxide in the air reacts with water to form carbonic acid:

$$CO_2 + H_2O \rightarrow H_2CO_3$$

The carbonic acid then reacts with the sodium hydroxide in a neutralization reaction. Sodium hydroxide reacted with carbon dioxide in the air to form sodium carbonate, which is less basic than sodium hydroxide.

$$2Na(OH) + H_2CO_3 \rightarrow Na_2CO_3 + 2H_2O$$

$$2\ NaOH + CO_2 + H_2O \rightarrow Na_2CO_3 + 2\ H_2O$$

Sodium carbonate is responsible for changing the colour of the indicator from blue to colourless.

Disappearing ink is very important in the textile industries as it is used as a tool in dressmaking[25] and also as a teaching material and to draw the design on the fabric or to mark something on the fabrics as the lines or marks will disappear after sometime. These inks are also used as paint. For example, it is difficult to determine which parts of an existing coat of white paint are not covered by a new layer similar color paint especially under poor lighting; disappearing ink can solve the problem[26-27]. It is also utilized in the marking system of various fields that needs proper placement of steps like sports training classes, dance classes etc.[28]. These pens are also used by the teachers at school or college level for preparing papers where questions are visible but answers remain invisible until a coloring assistant is used[3,4,14]. Now a day's these inks are used for committing various forgeries mainly related to banks, wills, property documents, etc.

Material and methods:

1. Blue disappearing ink pen (Vikson International)
2. Blue Erasable ink pen (Pilot)
3. Three variety of papers: White Copier paper (70gsm), Bond paper (90gsm) and Glossy paper (180gsm)
4. Mobile flash light
5. Photoshop 7 software
6. U.V. Cabinet
7. Iodine crystals
8. Sodium hydroxide
9. Video Spectral Comparator -8000

Preparation of Samples:

There are total 300 samples collected, 50 samples for each type of paper and pen.

Samples were prepared by using erasable pen & disappearing ink pen on three different variety of papers i.e. copier paper, bond paper & glossy paper.

Writings of erasable pen are removed by using pen erasure fitted at the tip of each pen.

The test samples were examined with different techniques like U.V. Cabinet, oblique light, Chemical examination methods, VSC etc.

Adobe Photoshop Software:

Adobe Photoshop is an editing software used in graphic designing and various other editing purposes. It offers a wide range of editing options like illustration, image enhancement, artwork and editing. Adobe Photoshop creates an immersive experience by simulation and creating alternative views of space. It is undoubtedly the most widely used software for editing and graphic designing. Adobe Photoshop is used in creating website layouts which are later programmed by developers.

We utilised Photoshop software to enhance the images of the samples in order to decipher the erased writings.

U.V. Cabinet:

Cabinet for Chromatographic analysis by ultra violet fluorescence is designed for viewing of fluorescent samples without interference from ambient light. It is a simple, fast and suitable technique for fluorescence analysis under lab conditions. Chromatogram viewing cabinet combines both long and short waves UV fluorescence and white light. The self-contained unit is designed for easy viewing and making of chromatograms and also for general fluorescence studies. One can view chromatograms at long U.V. range of 365nm or short U.V. range of 254nm. It can also be viewed with white light in a smaller table top which is capable of accommodating three methods for finding and recognizing parts[6,12].

Iodine Fuming Method:

Iodine fuming method was used to decipher the faded

writing on the different type of documents. For giving fumes to the samples, 1g Iodine crystals is placed in a closed fuming cabinet. The object bearing the erased writings is suspended from the roof of the cabinet. The erased writings was deciphered with the fumes of iodine[3,7]. Photograph of the deciphered writing must be taken immediately with the help of the camera.

Ammonia fumes were also given to the sample but it doesn't give desired result.

Sodium Hydroxide Method:

NaOH and KOH were sprayed over the faded handwriting written on the different kind of papers with the help of cotton(ear bud) to obtain a very fine mist[12]. Photograph of the deciphered writing must be taken immediately as it will be visible for a short time only. Ammonia was also applied over the samples to decipher the disappeared writing but it gives the negative test.

Video Spectral Comparator (VSC)

Video Spectral Comparator (Foster and Freeman) is the most widely used instrument available for the examination of suspicious documents. This instrument supports the non-destructive method for the examination of the questioned documents so that the documents remain intact. Video Spectral Comparator is an imaging device which allows differentiating between two inks, visualizing hidden security features, and helping to reveal alteration on the documents. This instrument is used to check the authenticity of various important documents like revenue stamps, wills, property documents, questioned signature or handwriting, banknotes, travel documents like driving license and other important documents. This system has also proven useful for faded or obliterated writing[4,5].

VSC works on the basic principle of light. It consist of various filters and light sources of U.V. light, visible light and infrared light which can be used for the examination of questioned documents.

VSC was the best way to decipher the faded writing on the different types of documents as its give the best result without affecting the paper samples.

Observation and Results:

After the examination of the ink sample on different types of the following result were obtained which are as follows:-

Decipherment using Adobe Photoshop software:

- Writings of erasable pen are removed by using pen erasure fitted at the tip of each pen.
- Samples were analysed in a dark room by using mobile phone flash light at different angles and another mobile phone was used to click pictures of the same.
- Images of the sample are enhanced or analysed by using Photoshop software in order to decipher the erased writings.

It was observed that all the writings on different variety of paper can be easily decipher by this method.

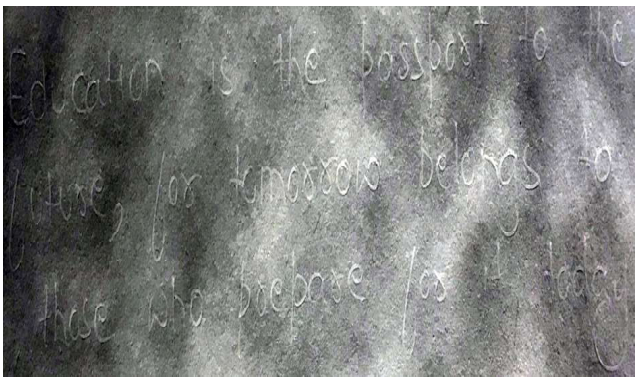


Fig. 1: Reappeared writings on copier paper

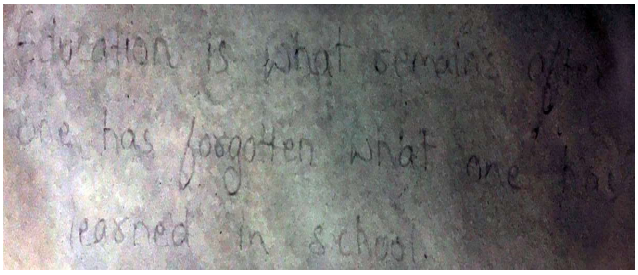


Fig. 2: Reappeared writings on bond paper

Fig. 3: Reappeared writings on glossy paper

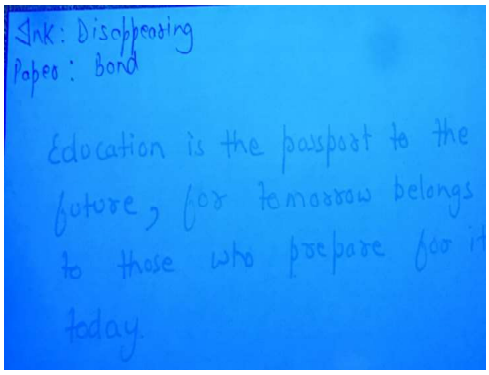
Decipherment using U.V. Cabinet:

- Samples were prepared by using erasable pen & disappearing ink pen on three different variety of papers i.e. copier paper, bond paper & glossy paper.
- Samples were analysed by keeping each sample in a U.V. Cabinet and analyzing each at short U.V. range (254nm) & long U.V. range (365nm).
- Photograph was taken by using a mobile phone.

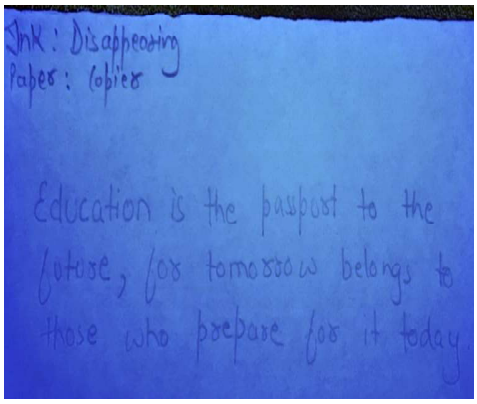
Table 1: Results of examination of invisible writing by using U.V. Cabinet

S.No.	Type of Ink	Type of paper	Examination Method	U.V. range (Long & short)	Result
1	Erasable	Copier	U.V. Cabinet	Both	Visible
2	Erasable	Bond	U.V. Cabinet	Both	Visible
3	Erasable	Glossy	U.V. Cabinet	Both	Visible
4	Disappearing	Copier	U.V. Cabinet	Long	Visible
5	Disappearing	Bond	U.V. Cabinet	Long	Visible
6	Disappearing	Glossy	U.V. Cabinet	Long	Visible

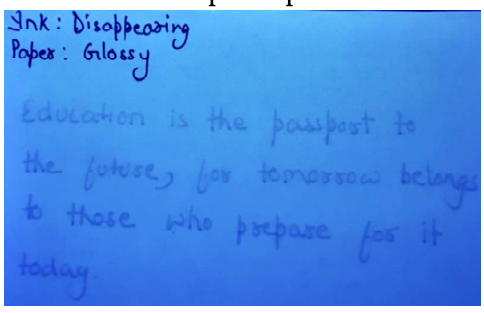
It was observed that the disappearing ink writings become visible at long U.V. (365nm) on all varieties of papers. The writings of erasable ink pen were visible at both long and short U.V. Light on all varieties of papers.



Bond Paper

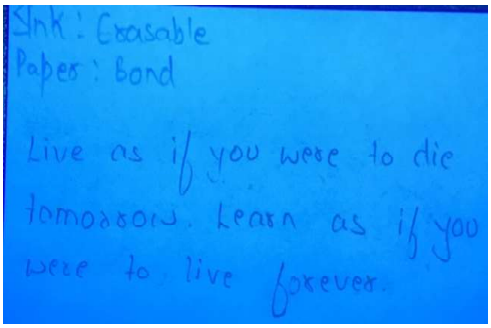


Copier Paper

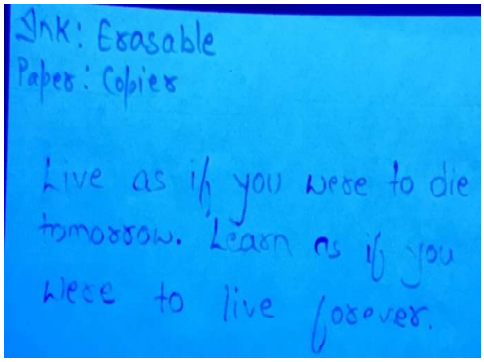


Glossy Paper

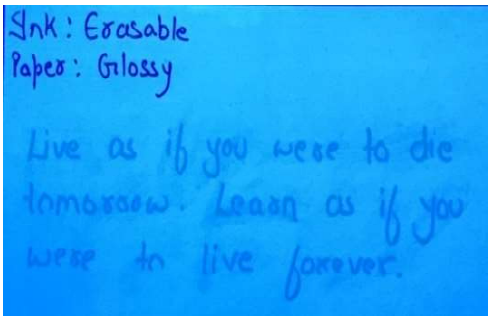
Fig. 4: Reappeared writing of disappearing ink on bond paper, copier paper and glossy paper



Bond Paper



Copier Paper



Glossy Paper

Fig. 5: Reappeared writing of erasable ink on bond paper, copier paper and glossy paper

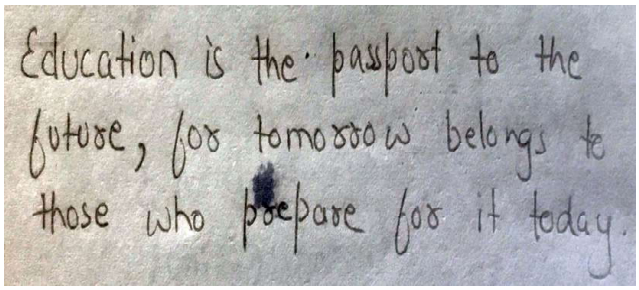
Decipherment using Iodine Fuming method:

The faded writing was visible when treated with the iodine crystals fumes. The paper samples were hanged over the iodine crystals which produced fumes inside the closed chamber resulted in the decipherment of disappearing ink. The mechanism behind visualization of the faded writing is that when the samples were written with the disappearing ink or erasable ink, it disturb the surface fibers of the paper so when the iodine fuming is done, the iodine sticks preferentially to the altered areas of the paper (20) and developed as brown writing. The camera was ready to capture the image as the writing was visible only for some time.

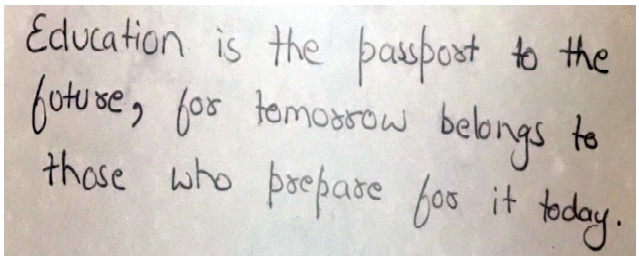
The invisible writing of both disappearing and erasable ink become visible when treated with the iodine crystals fumes.

Table 2: Results of examination of invisible writing by iodine fuming method

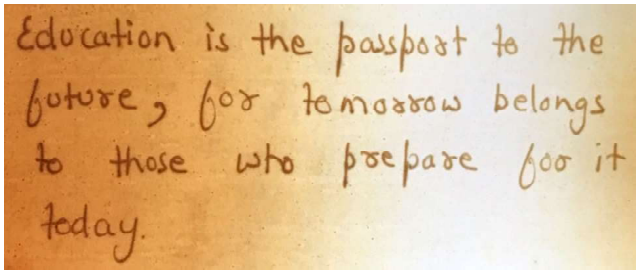
S.No.	Type of Ink	Type of paper	Examination Method	Result
1	Erasable	Copier	Iodine Fuming	Visible
2	Erasable	Bond	Iodine Fuming	Visible
3	Erasable	Glossy	Iodine Fuming	Visible
4	Disappearing	Copier	Iodine Fuming	Visible
5	Disappearing	Bond	Iodine Fuming	Visible
6	Disappearing	Glossy	Iodine Fuming	Visible



A- Copier Paper



B- Bond Paper

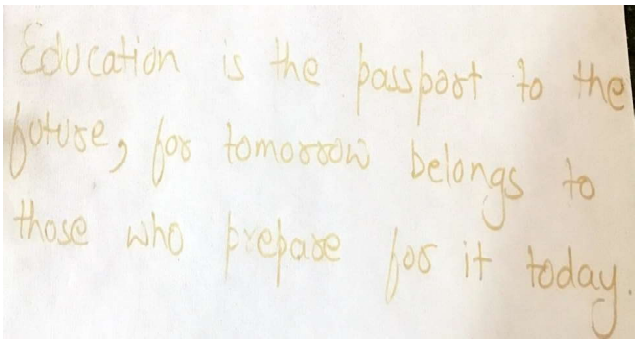


C- Glossy Paper

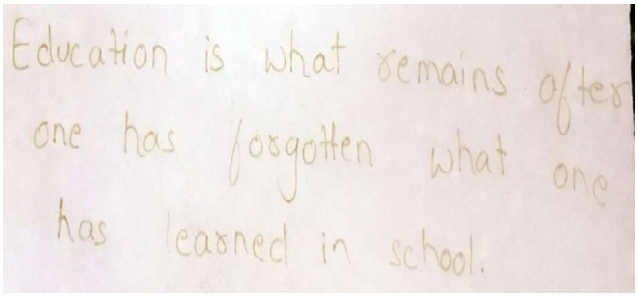
Fig. 6 : Reappeared writing of disappearing ink on A-copier paper, B-bond paper and C-glossy paper

Decipherment using Sodium hydroxide:

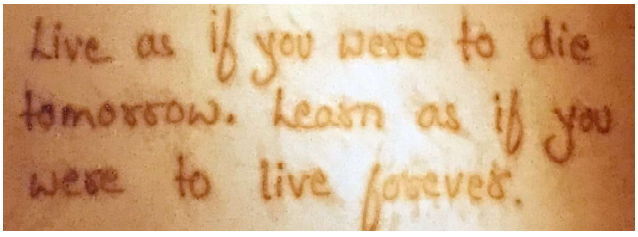
The disappearing ink writing was visible when treated with the alkaline solution such as NaOH. NaOH were sprayed over the disappeared handwriting written on the different kind of papers with the help of cotton(ear bud) to obtain a very fine mist. Similar results were obtained when KOH was used. Photograph of the deciphered writing must be taken immediately as it will be visible for a short time



A- Copier Paper



B- Bond Paper



C- Glossy Paper

Fig. 7: Reappeared writing of erasable ink on A-copier paper, B-bond paper and C-glossy paper.

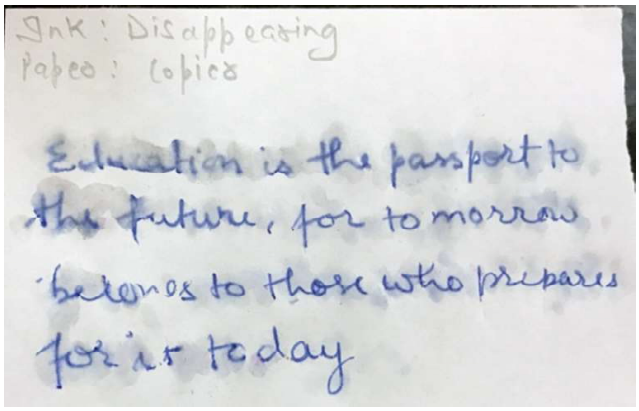
only. Photographs were taken with the digital camera. Erasable ink writing are not visible by this method.

Table 3: Results of examination of invisible writing by Sodium Hydroxide

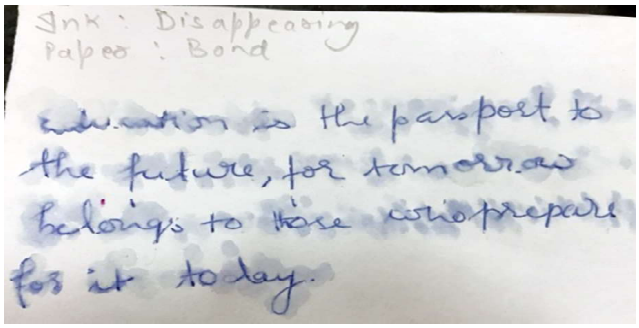
S.No	Type of Ink	Type of paper	Examination Method	Result
1	Erasable	Copier	NaOH	Not Visible
2	Erasable	Bond	NaOH	Not Visible
3	Erasable	Glossy	NaOH	Not Visible
4	Disappearing	Copier	NaOH	Visible
5	Disappearing	Bond	NaOH	Visible
6	Disappearing	Glossy	NaOH	Visible

Decipherment using Video Spectral Comparator-8000 (VSC)

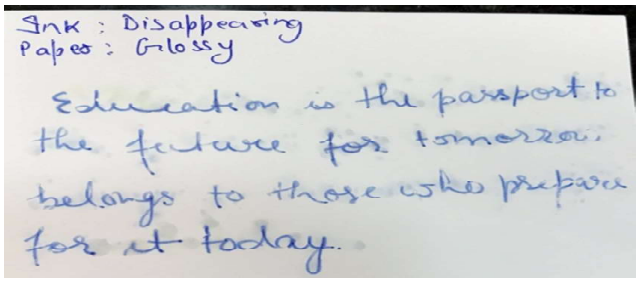
VSC works on the basic principal of light. The samples were examined under at different wavelength of lights with different filters and intensity. The samples were placed under the instruments and the lights were applied on it.



Copier Paper



Bond Paper



Glossy Paper

Fig. 8 : Reappeared writing of disappearing ink on bond paper, copier paper and glossy paper

When the ink interacts with the light at any observable events resulted in the decipherment of invisible ink because of its optical phenomenon. Both thermochromic ink and disappearing ink writings are visible under the U.V. light and Spot light of VSC-8000. Disappearing ink when react with the carbon dioxide it leaves a white residue, which was invisible to the naked eyes but when examined under the instruments (UV light) it gives fluorescence(24). Instrumental analysis for the examination of questioned samples is the best way as it is the non-destructive technique and it does not affect the samples.

Writing of both ink are visible under the spot light and U.V. light of VSC-8000 on all three variety of paper. Smudging effect of erasable ink pen rubber erasure was also visible when glossy paper was used.

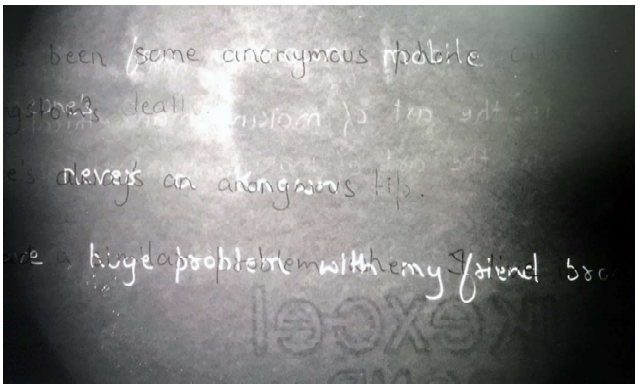


Fig. 9: Erasable ink writing visible under the spot light of VSC-8000

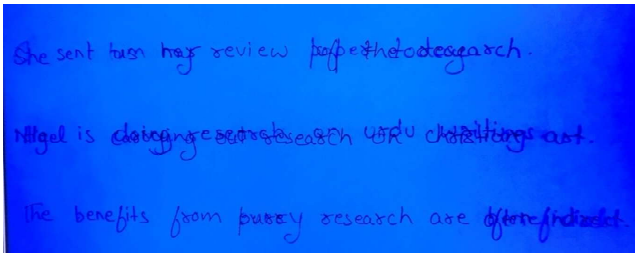


Fig. 10: Erasable ink writing visible under the U.V. light of VSC-8000

Conclusion

It is difficult to detect disappeared invisible ink writings by naked eyes. Due to easy availability and unique properties of thermal inks various cases of criminal activities are reported across the globe.

Analyzing the samples by using phone flash light and Adobe Photoshop software can be used to decipher all the writing including disappearing ink writings.

It was observed that when a person writes with extremely light pressure then it becomes a little difficult to decipher writings on bond paper because erasing method cause a larger damage to the fibres of bond paper.

It was also observed that the disappearing ink writings become visible at only long U.V. whereas erasable ink writings were visible at both long and short U.V. light on all varieties of papers.

Chemical examination reveal that iodine fuming method can be used to decipher both erasable and disappearing ink lines. Sodium hydroxide (NaOH) or KOH method can only be use to decipher disappearing ink lines.

Video spectral comparator can be used to restore invisible ink writings on all variety of paper. It was observed that in some cases smudging effect was too loud to read the erased writing. Although it is difficult to read the erased writing due to the smudging effect but it can be established that something was written at that place which was erased.

Conflict of Interest:

There is no conflict of interest.

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Effect of Thermochromic Ink on Different Types of Papers

Anamika Das[1], Suneet Kumar[2], Ahmed Sayeed[3]

ABSTRACT

Frixion Roller Thermochromic ink pens are incorporated with an erasure in each pen, which can be used to generate heat through friction which, in turn, decolourize the writings. Application of heat by other sources also have a similar effect. Thermal ink has a unique characteristic which makes it disappear, when heat is applied at a specific temperature. Due to this significant property of thermal ink, it is widely used for frauds. Easy availability and the unique characteristic of thermal inks attracts criminal minds and therefore increases criminal activities. The main purpose of this research paper is to describe different properties of thermal ink along with the derivation of an easy, inexpensive and non-destructive process to restore disappeared writings. Reaction of thermochromic ink with different varieties of papers has also been examined in this paper.

INTRODUCTION

KEYWORDS | erasable ink, thermal ink, ink analysis, forensic science

Invisible ink is prepared by special chemical process specifically for some industrial purposes. Invisible ink pen looks just like any other pens available in the market but the ink is made of different chemical composition. It is commonly known as magic pen. Auto-vanishing fluid inks are easily available in the market which raise great deal of concern.[4,14,15] Two kinds of invisible inks are: disappearing ink and thermal ink. Disappearing ink is a mixture of different chemicals which causes the ink to become visible for a very short time duration after which it disappears.[17-18] It works on the principle of acid/base chemistry and is an irreversible reaction. This research paper is focussed on thermal ink only.

Thermal ink is a type of erasable ink which is removed easily by the friction produced by rubbers incorporated in each pen.[9-13] It has different colours like red, blue, green and black. Such inks can be removed from the paper surface mechanically through erasure or by exposure to heat and cooling simultaneously. It is a type of viscous ink that depends largely on the heat generated during erasure which affects the solvent of ink. For the ink to disappear or fade the ink requires an external heat such as friction through eraser or through direct exposure to temperature.[4,5]

These inks are used for committing various crimes. Criminals use thermal ink pen to erase the original writing and then rewrite with the intent to defraud. Such obliterations are not visible to the naked eyes and are difficult to detect.[19,21,28] Forensic document examiners are very much familiar with these type of thermal ink ball-pen manufactured by Paper Mate, they are sold in UK under the name "Replay". "Eraser Max" is a new brand

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name for Replay erasable pens in the UK. A latest collection of erasable pens are manufactured by Pilot under the name "Frixion" erasable roller ball pen.[3,6]

A small eraser is fitted at the tip or end of the erasable pen which helps remove the writing. While removing with rubber eraser small traces of writing remained visible to the eyes. Rubbing the rubber eraser on the paper generates heat by the action of friction and decolourize the writings but does not abrade it.[3,6]

Pigment-forming microcapsules are made up of mainly three substances: first, leuco dye which can switch between colored and colourless forms, second, a color developer which chemically bonds with the leuco dye to produce color, and third is a temperature regulator which changes color according to temperature. The leuco dye is the one which actually determines the color but it can produce color only when it is chemically bonded with the color developer. The bonding of leuco dye

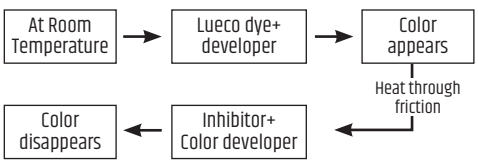

Figure 1: Reaction of Thermal Ink

and color developer is prevented by an inhibitor [color change temperature regulator] that inhibits bonding of the two above a particular temperature and makes the color disappear. There are several temperature regulators available that regulate colour change at different temperature.[7,22]

The solvent system used in thermal inks are leuco dye developer system. In the presence of a solvent an interaction between a colour former [leuco dye] and the developer results in the formation of the three components due to which colour change takes place.[20] Spirolactone molecule is commonly used as a colour former. One such possibility is CVL (CcrystalVvioletLlactone), which is colourless in grounded form. Opening of lactone ring gives colour to CVL, which results in increased conjugation due to the increased polarity or hydrogen bonding nature of developer. Phenols are generally used as developers. Some of the solvents which are commonly used in these inks are esters, acids having long chain aliphatic character, amides or alcohols.[2]

Properties of Thermal Ink

Erasable ink has acid-base sensitivity. It can be studied by adding 3M HCL or 3M H2SO4 to dry erasable ink at low temperature. This results in spreading of the colored form on the paper that helps to partially keep their colour at high temperatures. When acid is added to same dry ink after conversion at high temperature, it reverts back to coloured form.[1] However, addition of 3M NaOH or 3M NaCl showed negligible or little effect on the behavior of ink at high and low temperature.[8]

Examination through optical microscopy reveal the granular structure of ink which may be the result of micro-encapsulation of ink. Most of the granules are in the range of 1-2μm in size and some are upto 8μm in size. Most of the aqueous solutions does not affect the physical structure of ink granules, but some of the acids and bases can affect the granular structure by penetrating the granules and thus affects ink ability to change color.

Given enough time, the components of the ink reach their thermodynamically favoured colored form at low temperature and colorless at high temperature. Differential Scanning Calorimetry (DSC), when heated on a sample of black Frixion ink showed that the dominant endothermic transition takes place between 57°C to 60°C (without any exothermic transition in given range). When the ink was cooled, its dominant exothermic transition takes place at about −3°C to 0°C (without any endothermic transition in the given range). As observed it was found that these temperature ranges were consistent for dry ink, wet ink and aqueous solution inks like NH3, HClor NaOH added.[8]

The activation barrier that is responsible for the inter-conversion of different forms of ink components is high enough that at room temperature both the forms can coexist for a longer period of time. This is called as colour hysteresis which can be explained as the ink form at room temperature that depends on the way from which

that room temperature is reached or achieved.[8] It was found that α-anthracene terminated methoxy polyethylene glycol (An-PEG) aqueous solution can be used as a new type of ink to be written on conventional paper.[16,27]

METHOD & MATERIALS

Samples are made using Pilot Frixion Clicker Roller Pen (Blue) on three different types of papers. The papers used to prepare samples are White Copier paper (70gsm), Bond paper (90gsm) and Glossy paper (180gsm). There are total 90 samples recorded, 30 samples for each type of paper. In this process three ink removing methods are used i.e. erasure incorporated at the backside of each pen, hair dryer and domestic iron. A total of 10 samples with each method is prepared. Domestic freezer is used to restore all the writings. Observations were made by using a hand magnifying glass and unaided eye.

Observations

Frixion Roller pens are incorporated with an erasure at the tip of each pen which can be used

Figure 1: Pilot Frixion Clicker

to generate heat through friction which, in turn, decolourize the ink lines. This erasure can affect the physical properties of the paper depending upon the quality and type of the paper used.

We also used a domestic hair dryer to remove the writings made by thermal ink pen. It takes only 1 or 2 minutes to remove the writings from the paper. It was observed that the ink reappears in specific region of page with the movement of air stream.[6]

Domestic iron at a moderately hot, "two dot" setting was also used to remove the thermal ink writings. To protect the study paper, another sheet of paper is placed above the study paper before using the iron. The same effect was achieved when "one dot" setting of the iron was used to apply heat.[6]

All the samples with decolourized writings were placed in a domestic refrigerator (low temperature) to restore the writings. The following results were observed:

Sl.No.	Type of Paper	Method of Removal	Time taken to remove ink-lines	Reappearing Time at Low Temerature
1.	Copier Paper	Pen Erasure	1min.	45min
		Hair Dryer	1-2 min.	20min
		Domestic Iron	Few seconds	20min
2.	Bond Paper	Pen Erasure	1min.	1hour
		Hair Dryer	1-2 min.	20min
		Domestic Iron	Few seconds	20min
3	Glossy Paper	Pen Erasure	1min.	Doesn't reappear*
		Hair Dryer	1-2 min.	30min
		Domestic Iron	Few seconds	30min

Table 1: Pilot Frixion Clicker Roller [Blue]

It was observed that writings on the copier paper reappeared when removed with all the three methods i.e., by using erasure, hair dryer and domestic iron after putting it under the domestic refrigerator. Writings on the bond paper also shows similar results as shown by the copier paper.

Glossy paper reacts differently as compared to copier paper and bond paper. Glossy paper has a very smooth surface. When friction erasing

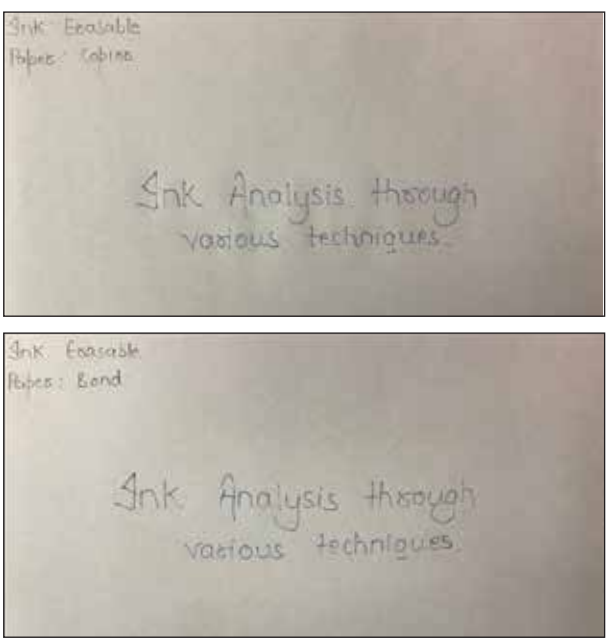

Figure 2 & 3: Reappeared writing on Copier, Bond papers respectively, by using domestic refrigerator (Blue)

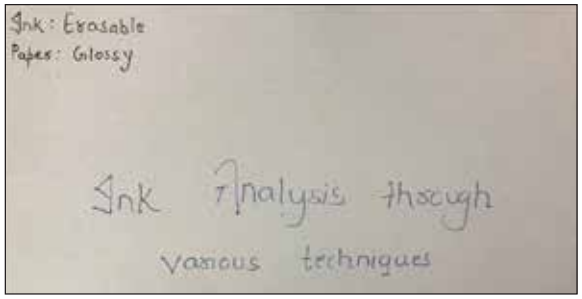

Figure 4: Reappeared writing on glossy paper using domestic refrigerator

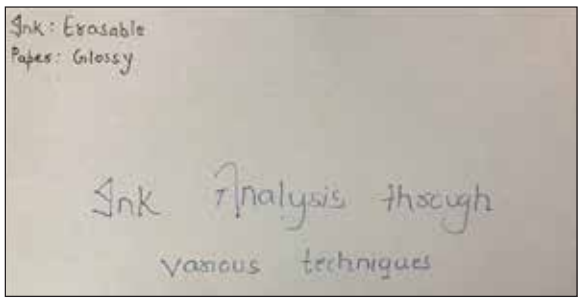

Figure 6: Reappeared writing on glossy paper using domestic refrigerator

method was used to remove ink lines from the glossy paper, it was observed that even after keeping it in a domestic refrigerator for sufficient time, the writings doesn't reappear. Only traces at the end of strokes reappeared. It was also observed that when ink lines were removed by using a hair dryer and a domestic iron then it reappears within 30 minutes when kept under the refrigerator.

CONCLUSION

It is difficult to detect disappeared thermal ink writings with naked eyes. Easy availability and unique quality of thermal inks attract criminal minds to indulge in increasing frauds. It was observed that applying heat by iron is the fastest method to remove thermal ink writings. This research paper provides information and alerts the forensic science community about the existence of thermal erasable roller ball-point pen and also describe an inexpensive, easy and non-destructive

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Figure 5: Few traces at the end of strokes reappeared when writings on the glossy paper is removed by using friction (rubber erasure)

method to decipher such writings. Some of the important features and properties of erasable ink are also elaborated in this paper. Restoration of disappeared writing by using an easily available domestic refrigerator provides a new avenue to detect these temperature dependent ink writings. Refrigeration method doesn't work on glossy paper when ink-lines are removed by pen erasure. In all other cases restoration by putting the samples in a refrigerator is possible. IJFMP

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A BRIEF REVIEW ON INVISIBLE INK: IT'S VARIOUS TYPES AND EXAMINATION METHODS

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ABSTRACT:

The analysis of ink in forensic examination has come up as a great challenge. There are a number of techniques and processes available for ink forgeries. Some of them are tricky but routinely practiced to commit crimes related to deeds, bills, cheques, will, contracts and certain other financial documents. Invisible ink or magic ink is one of the modern technology widely used for committing financial forgeries. It is of two types, erasable ink and disappearing ink. Disappearing ink fades away without leaving any trace after few hours upon exposure to CO_2 (any other acid) in the air. Another type of ink is erasable ink which can be easily removed by certain rubbers incorporated in each pen. The present review represents the type, nature and different properties of invisible ink. Different techniques used to decipher these invisible inks are mentioned.

Keywords: Invisible ink, erasable ink, disappearing ink, magic ink, forensic science, ink analysis

INTRODUCTION:

With the increase in literacy, shrinking job opportunities , globalization of the economy and access to superior technology, white collar crimes have increased dramatically. Increasing Research and Development in various fields of science has led to a increase in more advanced technology which results in both positive as well as negative applications(1). Banks are one of the most common and easy target for a forger where the entire banking system is based on physical documents. Criminals cheat banks with false identification, bank instruments, fabricated or altered cheques and stolen financial information. It is observed that most of the bank frauds cost millions of rupees and losses are mounting day by day(2). Other financial related crimes like those related to deeds, will, contracts, bills, and various other documents are also increasing.

It has been observed that criminals are continuously using and developing new *modus operandi* using new advanced technology to cheat different organization and individual victims(1). Erasable and disappearing ink, a.k.a. magic inks are among the latest techniques used by criminals in committing different forgeries. Development and advancement of new research and technology has enhanced the availability of different types of pen with magic ink which are being used by criminals for forgery. Vanishing ink/invisible ink are the type of

ink which are prepared by special chemical reactions. Invisible ink pens, commonly called as magic pens looks like other normal ink pen, but there ink composition differs from other pens. They enter the country through illegal means and are available at very cheap price which attracts the common people. Auto-vanishing fluid inks are available in the local market which makes them accessible to local people and raises a great deal of concern.

It has been revealed in literature review that there are mainly two types of ink that are used to prepare invisible ink pens - (i) Thymolphthalein based (disappearing ink), (ii) Thermochromic based ink (thermal erasable ink) (2). Recent years have witnessed that these inks are being used in legal documents which results in heavy loss to the third party because these inks leave no sign of chemical or physical alteration or deletion on the document. For example, suppose a promissory note signed by a normal regular ink but the details like amount are filled by a disappearing ink. After the disappearance of vanishing ink, a different regular ink pen can be used to fill a different amount, causing a fraud(12).

Ink in general is a composition of pigments or dyes along with additives to bring about desired physical properties. Today, a variety of ink composition is available consisting of different combination of organic, inorganic and synthetic material with different characteristics and properties.(14)

DISAPPEARING INK:

Disappearing ink is a substance consists of a mixture of chemicals which makes the ink visible to the eye for a short duration of time. It is an irreversible reaction based on the principle of acid/base chemistry[3].

Disappearing ink is a water soluble pH (acid-base) indicator that when exposed to air changes from a colored to a colorless substance. The chemistry behind this reaction is the water present in the ink reacts with CO_2 present in the air to form carbonic acid. The carbonic acid formed reacts with sodium hydroxide to form sodium carbonate. Due to this reaction neutralization of the base, pH changes and makes indicator colorless, hence ink disappears [3,11,12,13,14]:

Carbon dioxide(CO_2) in the air reacts with water(H_2O) to form carbonic acid(H_2CO_3):

$$CO_2 + H_2O \rightarrow H_2CO_3$$

The neutralization reaction :- sodium hydroxide + carbonic acid -> sodium carbonate + water:

$$2\ Na(OH) + H_2CO_3 \rightarrow Na_2CO_3 + 2\ H_2O$$

$$2\ NaOH + CO_2 + H_2O \rightarrow Na_2CO_3 + 2\ H_2O$$

- Sodium hydroxide and CO2 reacts with each other in the presence of air to form sodium carbonate. Sodium carbonate is less basic as compared to sodium hydroxide.

- Sodium carbonate changed the colour of the indicator from blue to colourless. The transition range of thymolphthalein is pH 9.3-10.5, above this pH range it is blue and below this range it is colourless.

- Only colourless residues are left behind and alcohol gets evaporated(4).

Disappearing ink is a mixture of acid-base pH indicator like thymolphthalein, ethyl alcohol, base like sodium hydroxide solution, and water at pH 11.The most common pH indicators used in the preparation of disappearing inks are thymolphthalein ($C_{28}H_{30}O_4$) and phenolphthalein ($C_{20}H_{14}O_4$).

In solid form they both are found as white powders. Thymolphthalein gives blue color so it is used to prepare blue ink and phenolphthalein gives pink color so it is used to prepare red ink. Mixture of thymolphthalein and phenolphthalein is used to generate a purple solution according to their pH values(3). Amount of sodium hydroxide and thymolphthalein/ phenolphthalein in a solution decides the fading period a disappearing ink, it range from a few hours to few days. These vanishing ink on paper may not be detected even under high-resolution magnifier, IR light and UV light(3,12).

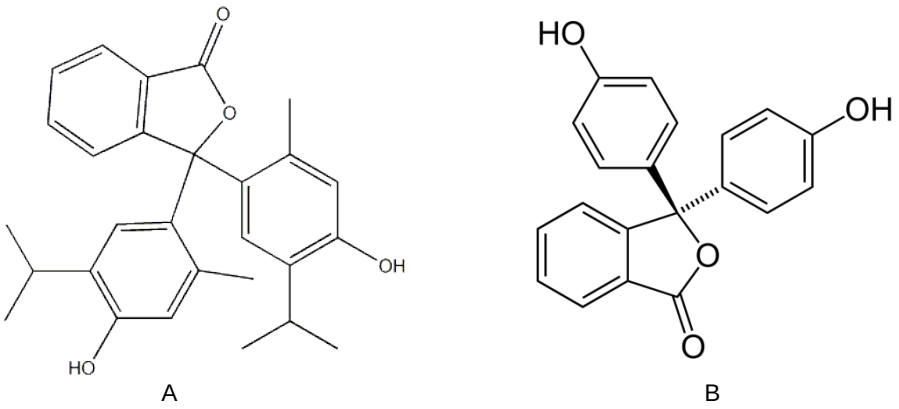

Figure 1: A- Thymolphthalein, B- Phenolphthalein(13)

Sodium hydroxide with thymolphthalein gives blue color ink, with phenolphthalein gives pink color and the mixture of all three gives purple color. As the concentration of sodium hydroxide in a solution increases the stability of ink also increases, low or decreased concentration of sodium hydroxide produces colourless writing. Increasing concentration of phenolphthalein and thymolphthalein also increases the stability of writing(4).

Disappearing ink are used for a variety of purposes, For example, it is used as a marking tool by the painters. in sports, dance classes, textile industry, fashion industry and many other different activities which require a marking system(3,4,14). It is also used as a tool in education system by the teachers while preparing papers, only questions are visible and the answers became visible by using a colouring assistant(3,4,14).

OTHER TYPES OF INVISIBLE INK:

IR-active invisible ink

Infrared- active invisible ink shows high absorption in IR spectral region, but it is transparent in the visible region of the spectrum. There are two types of IR-active ink, IR absorbing ink and IR penetrating ink. Silicon (IV) 2,3 naphthalocyaninebis (trihexyl-silyloxide) (SiNc) based Infrared-active invisible ink shows strong absorbance at 790nm and highly transmitting characteristics in the visible spectrum. Colorants which are chemically and physically compatible with the ink base are used in the preparation of IR invisible ink. Infrared inks that satisfy these requirements are further mixed with suitable binders and pigments. Examples of pigments which are used mostly are BASF Lumogen IR 765, 729nm SiNc and Lumogen IR 788 and binder such as polyethylene terephthalate resin (PET) are used(15).

UV-active invisible ink

Ultra Violet - active invisible ink fluoresce due to the presence of dyes upon exposure to UV light source. When excited by UV light, a portion of energy is absorbed by the material and fluorescence is emitted in the visible range. Some invisible inks which are commercially available glow brightly in a variety of colors when exposed to UV light. Tonic water, optical brighteners containing laundry detergents, body fluids and soap are some of the examples of UV-active ink materials(15).

ERASABLE INK:

Thermal or thermochromic ink is a type of erasable ink which is removed easily by the friction produced by rubbers incorporated in each pen. It has different colors likes red, blue, green and black. Such inks can be removed from the paper surface mechanically through erasure or by the exposure effect of heat and cooling simultaneously. It is a type of viscous ink that depends largely on the heat generated during erasure which affects the solvent of ink.The fading of this type of ink requires an external heat factor such as friction due to eraser or by direct exposure of temperature(6).

These inks are used for committing various crimes. Forensic document examiners are very much familiar with these type of erasable ink ball-pen manufactured by Paper Mate, they are sold in UK under the name "Replay". "Eraser Max" is a new brand name for Replay erasable pen in UK.. A latest collection of erasable pens are manufactured by Pilot under the name "Frixon" erasable roller ball pen(3,9).

A small eraser is fitted at the tip or end of the erasable pen which helps to remove the writing. While removing with a rubber eraser a pale trace of writing remains visible to the unaided eyes. Rubbing the rubber eraser on the paper generates heat by the action of friction and decolourize the ink line but does not abrade it(3,9).

Pigment forming microcapsules are made up of mainly three substances: first, leuco dye which can switch between coloured and colourless forms, second, a color developer which chemically bonds with the leuco dye to produce color and third is a temperature regulator which changes color according to temperature. The leuco dye is the one which actually determines colour but it can produce colour only when it is chemically bonded with the colour developer. The bonding of leuco dye and colour developer is prevented by an

inhibitor(colour change temperature regulator) that inhibits bonding of the two above a particular temperature and makes the colour disappear. There are several temperature regulators available that regulate colour change at different temperature(16).

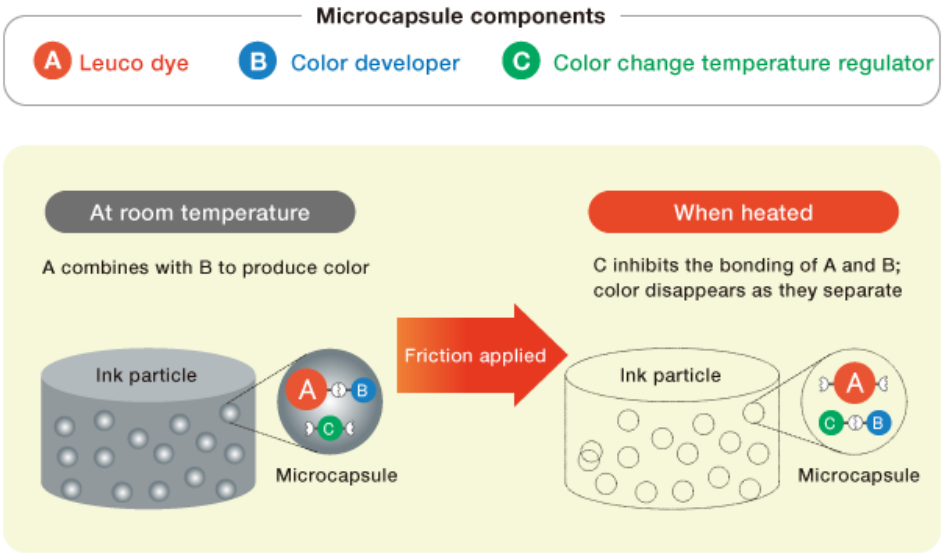

Figure 2: Frixion erasable ink(16)

Leuco dye developer solvent system is used in thermochromic/thermal erasable inks. The leuco dye-developer-solvent system is a thermochromic pigment present in a polymer shield. Color change takes place due to the formulation of three components based on the interaction of a color former (leuco dye) with the developer in the presence of a solvent. Colour former may be a spirolactone molecule. Such one possibility is the CVL (CcrystalVvioletLlactone), which is colorless when in grounded lactone form. CVL attains colour when lactone ring opens. This is result of increase in the polarity or hydrogen bonding ability of the environment (developer) increasing the conjugation. Generally, phenols are used as developers. Solvents used in these inks are amides, esters, alcohols or acids having long chain aliphatic character(2).

The solvent system used in thermal inks are leuco dye developer system. In the presence of a solvent an interaction between a color former (leuco dye) and the developer results in the formation of the three components due to which color change takes place. Spirolactone molecule is commonly used as a color former. Such one possibility is the CVL (CcrystalVvioletLlactone), which is colorless when in grounded lactone form. Opening of lactone ring gives color to CVL, which results in increased conjugation due to the increased polarity or hydrogen bonding ability of the developer. Phenols are generally used as developers. Some of the solvents which are commonly used in these inks are esters, acids having long chain aliphatic character, amides or alcohols(2).

Properties of thermal ink:

Erasable ink has acide-base sensitivity that can be studied by adding 3M HCL or 3M H_2SO_4 to dry erasable ink at low temperature which results in spreading of the coloured form on the paper that help to partially keep their colour at high temperatures. Addition of these acids to these same dry ink colors after conversion to the high-temperature, colorless form caused

them to revert to their coloured form. However, adding of 3M NaOH or 3M NaCl had negligible or very little effect on the behaviour of ink at high and low temperature(17).

Examination through optical microscopy reveal the granular structure of the inks which may be the result of micro-encapsulation of ink. Most of the granules are in the range of 1-2 μm in size and some are upto 8 μm in size. Most of the aqueous solutions does not affect the physical structure of ink granules, but some of the acids and bases can affect the granular structure by penetrating the granules and thus affects ink ability to change color.

Given enough time, the components of the ink reach their thermodynamically favored colored form at low temperature and colorless forms at high temperatures. Differential Scanning Calorimetry (DSC), when heated on a sample of black FriXion ink revealed that the dominant endothermic transition takes place at about 57°C to 60 °C (without any exothermic transition in given range). When the ink was cooled, its dominant exothermic transition takes place at about −3°C to 0 °C (without any endothermic transition in the given range). As obesrved it was found that these temperature ranges were consistent for wet ink, dry ink, and aqueous solution inks like HCl, NH3, or NaOH added(17).

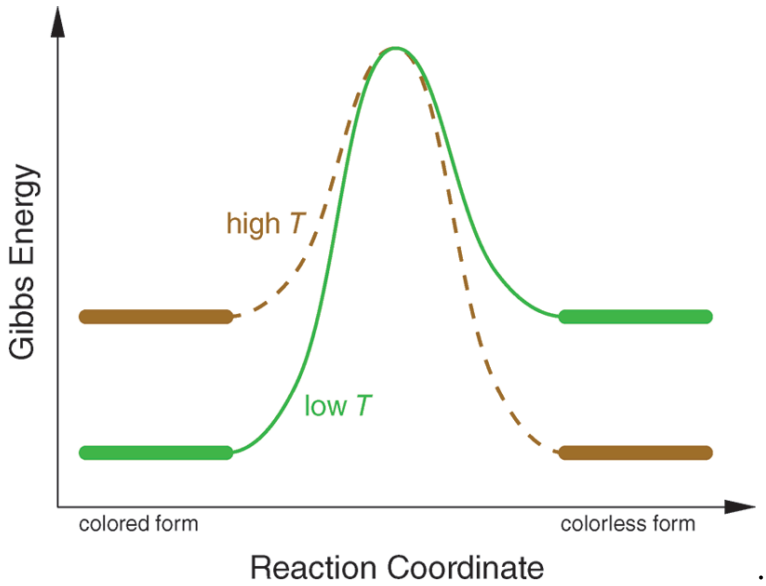

Figure 3: Activation barriers between the coloured and colourless forms at different temperatures.

The activation barrier that is responsible for the inter-conversion of different forms of ink components is high enough that at room temperature both the forms can exist for a longer period of time. This is called as colour hysteresis which can be explained as the ink form at room temperature that depends on the way from which that room temperature is reached or achieved. To begin with coloured ink below the color transition range at point A, the ink traverse through the upper pathway as it is heated by the action of rubbing and attains a high temperature (~60 °C) before changing the color and then ends up at point B. At point B when the ink gets cooled slowly, it traverse through the lower pathway and attains low temperature (~0 °C) before changing of the color and then ends up at point A. The cooling pathway of the

ink gets changed when the high temperature or colourless form of the ink gets rapidly cooled to low temperature with liquid N_2 , this kinetically traps the ink in colourless state. When this ink is warmed up back from these low temperature, it gets converted from colourless to coloured form(17).

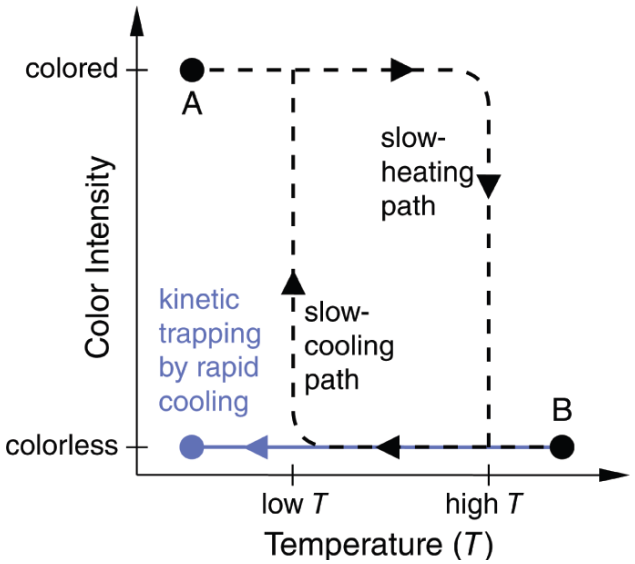

Figure 4: Schematic colour hysteresis curve for the thermochromic ink, including the kinetic trapping of the colourless form of the ink(17).

DIFFERENT EXAMINATION TECHNIQUES:

1. Color measurements

Color measurements are very useful evidence and can be examined by changing of inks color. The color strength (K/S) for erasable and disappearing ink can be determined on paper sheet samples by calculating the value of K/S from the Kubelka- Munk equation.

$$K/S = (1-R)\ 2\ /2R$$

Where,
R= average observed reflectance
K= absorption coefficient
S= scattering coefficient
K/S= corresponding strength of colour

The corresponding K/S value can be calculated for each ink sample using Data Color SF 600+ Relative color(6).

2. Colour strength measurements

Fading time :Fading time of writing is defined as the time from writing to its colour disappearance (complete fading).
Different brands of disappearing ink were spread on the surface of paper samples and allow drying at room temperature then measuring the reflectance from two hours up to three days and calculating the changes in value of the color strengths (K/S) using the Kubelka-Munk equation. The change in color strength values (K/S) give an indication on fading of inks**,**

Where each color is measured at 254nm. It was found that Phenolphthalein loses its color faster than Thymolphthalein.

Similarly, different brands of blue erasable ink are disseminated on surface of one type of paper sheet samples and allow them to dry at room temperature. Then, the fading of ink color is determined for each sample by measuring the reflectance of ink (R) at different time intervals, ranging from two hours to three days, either at room temperature between 20-25^{0}C or by exposing to ultra violet light at 254 nm(6).

3. Microscopic examination

The optical examination of documents was carried out by hand magnifiers and stereo microscope (magnification 20X-60X) with direct light and oblique light(6,12). The whole document is examined carefully with the help of different tools to find out minute differences like lingering effects, use of erasures or traces of erasures, different strokes og ink lines etc. Different types of tools like hand magnifiers, binocular and illuminated magnifiers are available which can be used for microscopic examination of documents. Strokes of invisible ink contain minute streaks and striations which can be used to individualize the writing(7).

4.Examination with VSC

Video Spectral Comparator 6000 (VSC6000) or other different versions of VSCare used for the optical examination of documents. VSC is one of the most versatile instrument which can be used for non-destructive examination of different documents by using different instrumental parameters. It is very easy to use and gives instant results. VSC consist of an imaging device which helps the examiner to analyze different inks, examine alterations, and study hidden security features. VSC allows the forensic examiner to identify forgery in questioned documents by using a special inbuilt feature of spot illumination of infra-red, visible or UV portions of the spectrum which makes the hidden strokes glow and disappeared ink fluoresces under the influence of ultra-violet light(6,7,12,14).

5.Examination with Projectina Docucenter4500

Projectina Docucenter is an instrument used for the examination of photo-copied and scanned documents. Projectina is especially designed to examine documents by the method of superimposition and side by side comparison. It is also called as a micro-projector. The main feature of this instrument is that it examine and compare objects which appear to be identical. It proves that two objects that first appear to be identical have in fact many minute differences(7).

6.Electrostatic detection apparatus (ESDA)

In late 1970's Foster and Freeman commercially produce Electrostatic Detection Apparatus (ESDA). It is a non-destructive method to examine indentations in a suspected document. It is a very easy to use technique, it helps to produce life-size transparencies of indented writing without causing any damage to the original document. It does not interfere with other forensic test and the same document can be processed number of times without any loss of sensitivity. This technique can be used to individualize the writer and can also be used to reveal invisible writing.

7.Chemical Method

Ammonium NH_3 vapour was used to decipher the disappearing ink. When the disappearing ink comes in contact with NH_3 vapour, invisible entries turned blue successfully without harming the paper/substrate. Similar results are observed by using iodine fuming and dilute

sodium hydroxide(NaOH). Reappeared writings were photographed using digital camera as the writing will remain visible only for few seconds and then again becomes invisible (3,7,12,14). It was found that NaOH solutions when sprayed on paper may harm the paper/substrate.

8.Heat effect

Heat can be used to disappear erasable ink writing. This can be studied by using oven, electric iron and hair dryer(7). Disappearing ink doesn't have any effect of heat.

9.Examination under refrigerator (at low temperature)

Invisible writings can be revealed by putting the samples in the freezer of any household refrigerator. At such low temperature of the refrigerator the thermal ink become coloured and visible. It is a very simple, easy to use, sensitive, fast, cost-effective and non destructive technique to examine and detect alterations and manipulations on a suspected document(2).

10.Examination of physical properties of paper

When erasures are used on a paper, some of the surface layer is removed by the erasing process which also affects the thickness and other physical properties of the paper. Thickness of the paper should be measured from different positions of the document. Roughness and texture of the document are also measured by using microscope. The thickness of the paper will decrease at positions where erasures are used due to the removal of the coating layer. As thickness decreases, roughness increases due to the removal of the coating layer from the surface of the paper(7). Different mechanical properties of the paper are also studied by different test like tearing resistance test, strength test, elongation test and bursting test.

11.Examination of chemical composition the Ink

Erasable ink consists of different components like elastomeric polymer, volatile solvent, non-volatile solvent, pigments, dyes, and lubricants(7)**.** Disappearing ink are mostly made by using thymolphthalein, water, sodium hydroxide and ethyl alcohol(3,12). Examination of composition of the inks are very important.

Difference between erasable and disappearing inks on paper using Scanning Electron Microscopy (SEM) : Erasable ink remain on the surface and are not absorbed by the paper as it belongs to the viscous ink family. On the other hand disappearing inks are absorbed by the paper as it belongs to the liquid inks family(6,7).

Table 1: Difference between disappearing ink and erasable ink(6)

S.No.	CATEGORY	ERASABLE INK (THERMAL INK)	DISAPPEARING INK
1.	COLOR	All Color	Pink(red) & blue
2.	Shape of Strokes	Ink on the surface of paper	Ink penetrates the paper
3.	Erasing method	By erasure or heat	A spontaneous erasure
4.	Type	Viscous writing material(dry)	Liquid writing material
5.	Colorant material	Pigments & dyes	Indicators
6.	Effect of alkali sol.	No effect	Reappearing of ink
7.	Pressure of writing	Smooth	Rough

8.	State of ink on the paper	On the surface of paper	penetrate

CONCLUSION:

Invisible ink pen are easily available in the market and can be used by the forger for committing forgeries. Once the ink becomes invisible, it becomes difficult to detect it by naked eyes. So, it becomes very important to develop a practical and non- destructive method to decipher these inks easily. Invisible inks are becoming one of the latest techniques used in committing forgeries in writing various bank cheques, withdrawal forms, wills, deeds and other important documents. Many different varieties of these pens are easily available locally, this makes easy for the criminals to use them and commit forgeries. Various examination methods are available to decipher such vanishing inks like VSC, ESDA, Projectina docucenter 4500, chemical methods etc. Invisible inks are abused by the criminals because of its easy availability and unique quality, therefore it becomes our duty to create awareness about this issue among different investigating agencies and laboratories to ensure that it is being used judicially. It will be of great advantage to the society as well as law and enforcement agencies.

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Pen Pressure: An Important Tool in Online Signature Verification

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Abstract

Over the years, many different methods and software have been developed to distinguish between genuine and forged signature verification. Automatic verification of online signature has been a compelling task with greater practical applications. This paper focuses on the pen pressure and other pen dynamics to differentiate between a forged and a genuine signature. Pen pressure is the force applied by the fingers in the process of writing and it is one of the many characteristics which the forensic experts use for comparison. Other pen dynamics like velocities, forces, varying orientation of the pen, and the way in which a signer grasps a pen are also an important in examination process. Traditional offline verification systems are replaced by automatic online verification systems in the commercial market, as these systems are more reliable, less time consuming, accurate, precise, and needs less efforts. The present review represents the importance of pen pressure, different online signature verification techniques based on pen pressure and other features in differentiating genuine and forged signature.

Key-Words: *Online verification, pen pressure, signature, handwriting, forgery, forensic science.*

Introduction

Pattern recognition has been a widely used tool in forensic science, from analysis of unknown compounds to individual personal identification. The identity of a person can be verified or determined through pattern recognition of various biometric traits such as palm print, iris, fingerprint, retina, face, odour, ear, gait pattern, signature, voice recognition, hand vein, or genetic information like DNA. The biometric traits range from various individual physical characteristics (such as face, iris, fingerprint) to behavioural attributes (such as handwriting or signature) [1, 12].

In forensic handwriting and signature examination, experts compare the characteristic writing features of the questioned handwriting with the control specimens. Handwriting is an acquired skill, a task which takes place by coordination of nervous and muscular system. It is also known as a neuro-muscular task. Handwriting of every individual is unique and it changes during our lifetime with experiences and learning. Handwriting identification is based on the principle that, while handwriting within a language tends to be alike to the degree that we can meaningfully read it, there are individual features that distinguish one person's writing from that of another. Just as no two people are exactly alike, the handwriting of no two people are exactly alike in their combination of characteristics. There are, of course, natural variations within the handwriting of each individual. these variations must be closely and

carefully studied by the examiner, so that he can distinguish between what is a "variation" and what is a "difference".

A technological revolution has affected the world of writing in these recent years. Most companies today need to have lower costs for archiving and transmission of document and in the same time it was posed the security question. The answer has been the digital biometric signature: Biometrics is actually the science of using digital technologies to identify a human being based on the individual's unique measurable biological characteristic. Applied to handwriting, biometrics enable the comparison between digital signatures in order to avoid falsification and disclaimer [3].

In this present study importance of one of the individual characteristics of handwriting are shown i.e. PEN PRESSURE. Pen pressure is the force or pressure applied by the fingers of an individual during writing. The heavy pressure applied on the paper cause indentations behind the paper [3]. It has been mentioned in the literature that natural pen pressure variations are an integral part of an individual's signature. The variations are individual to such an extent that it is highly unlikely to have two authors with well-developed signatures of normal length with the same pressure patterns. Besides, the pressure patterns of a well-developed signature of normal length are extremely difficult to duplicate in the forged signature. Signature verification computer systems using pen pressure as an identifying characteristic were developed since 1970s. However, normal course of business signatures were mostly written on pieces of paper and pressure patterns of the signatures could not be easily recorded or converted from the paper to be examined [1].

Questioned document examiners pay more attention to individual characteristics other than pen pressure like slant, letter formation, pen lifts, embellishments, movement, form, height proportion, spacing, connections, speed, etc. They give less importance to pen pressure which is also one of the unique individual characteristics of handwriting. Similarly, a forger while doing forgery pay more attention to formation of letters, connections, slant and other individual characteristics but give less or no attention to pressure points. The examiner and forger both forget that pen pressure is also one of the most important individual characteristic of handwriting which can be used to differentiate between genuine and forged document or signatures.

A handwritten signature is biologically linked to a specific individual. Modern forensic document examiners commonly compare a suspect signature with several examples of known valid signatures. They look for signs of forgery which include: Signatures written at a speed which is significantly slower than the genuine signatures; frequent change of the grasp of the writing implement; rounded line endings and beginnings; poor line quality with hesitant and shake of the line; retracing and patching; and stops in places where the writing should be free.

Genuine Signatures and Writing

Genuine signatures are naturally written signatures that a writer develops as a personal identifier [10]. They are the combination of writing characters which are consistent with natural conditions surrounding the signed document. Authentic writer writes freely or subconsciously because he/she has been

signing his signatures for years. Authentic signature is rapid, smooth, rhythmic, carelessness or obvious corrections are normally seen. Authentic writer has no fear of being accused as a forger does [14].

Characteristics

- Rapid.
- Rhythmic
- Obvious corrections are normally seen
- Introduce certain other forms
- Smooth
- Flowering ending stroke
- Natural free flowing Appearance

Forged Signature and Writing

Forgery is an attempt made by a person to defraud another by falsely making or altering a signature or writing. Forgery basically means making a false document with intend to defraud [14].

Characteristics

- Unnatural appearance
- Lack of individuality
- Slowly written
- Study attention to the formation of letters
- Blunt beginning and ending strokes
- Lack of rhythm
- Appearance of being drawn

Pen Pressure

Pen pressure is the amount of pressure exerted on the pen point and is the result of the rhythmical contraction and relaxation of muscles during the act of writing. It is the force exerted by the pen on the paper during writing which appears to be a discriminating parameter between individual writers [1]. Person identification on the basis of normal hand-writing samples becomes easy and improved if the pen-force signal is known. Thus, pen pressure signal is an important source of information in handwriting or signature verification systems. Osborn stated the importance of pen pressure in signature identification. He expressed that "a delicate, inconspicuous, and almost wholly unconscious variation in line quality, weight of stroke, location of emphasis, smoothness of line and manual skill that has high identifying value. As shown in the "quality of line," and especially the location and character of emphasis or unconscious shading, the variation in this feature is one of the most important evidences of genuineness and forgery" [3,10].

Those who write with heavy pressure are slow writers. Illiterate persons ordinarily write with heavy pressure. Every individual have different pen pressure habits in their handwriting, so this feature is very useful to detect different forgeries e.g. carbon paper forgeries etc. The variations in pen pressure are usually manifested in the contrast of darkness and lightness of the ink stroke. However, the nature of the ink and the absorbance of the paper surface may hinder the examination. In addition, the pen pressure pattern of the entire writing could hardly been visualized by tradition photographic and lightening techniques [3].

There are number of methods discovered to measure pen force. Sometimes, it is measured by using transducer in writing

instrument or under the writing surface so so that its time function can be noted. In forensic handwriting analysis, pen force can also be measured from the static properties of the handwriting, i.e., paper characteristic, trace thickness and depth. Other methods which use different pen dynamics are also available [4,5].

Handwriting Attributes (Features)

Features are quantitative measurements that can be obtained from a handwriting sample in order to obtain a meaningful characterization of the writing style. These features can be obtained from the entire document, or from a paragraph, line or a word. Generally two types of features are considered i.e. conventional features and computational features.

Conventional features are the handwriting attributes that are commonly used by the forensic experts in document examination. These features are obtained from handwriting by visual and microscopic examination. Software like FISH (Forensic Information System of Handwriting) are also used to narrow down the search. Computational features are those that have known software/hardware techniques for their extraction. They can be determined algorithmically, e.g., by software operating on a scanned image of the handwriting. Computational features can be divided into macro and micro-features, depending on whether they pertain globally to the entire handwritten sample, e.g., darkness, or are extracted locally, e.g., contour variations [16].

Different Methods of Pen Pressure Examination

Research on various computerized methods for online signature verification has been reported. There are number of software available which can be used for this purpose. Various machine learning algorithms has also been developed for examining scanned paper documents.

Examination of Scanned Documents

Software for recognizing handwritten scanned documents has many applications in the field of forensic. Different machine learning algorithm are used for the purpose of examination. In case of scanned image examination, scanned images are mostly stored as grey scale image of discrete pixels, which can later be converted to a pure black and white image by binarization algorithm [16].

Namirial GrafoCerta method

Speed and pen pressure are two important individual characteristic of handwriting and a research was carried out to explain the correlation between pen pressure and speed. It was found that all people have had more difficulty in slowing their movement rather than accelerating. In all the slowed signature there are more pauses, more fragmentation of shape and more overhead movements, furthermore people put into words their difficulty. Index of deceleration goes from 3,60% to 84,37%, index of acceleration goes from 6,25 % to 277,97% . This research was done to find out if there is a constant correspondence between speed and pressure, if pressure always lightened in acceleration and if it always make heavy in deceleration. In this paper correlation between pressure and speed is exposed [3].

Dynamic Handwriting Features

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In the study it was investigate if computer-measured dynamic features (duration, size, velocity, jerk, and pen pressure) differ

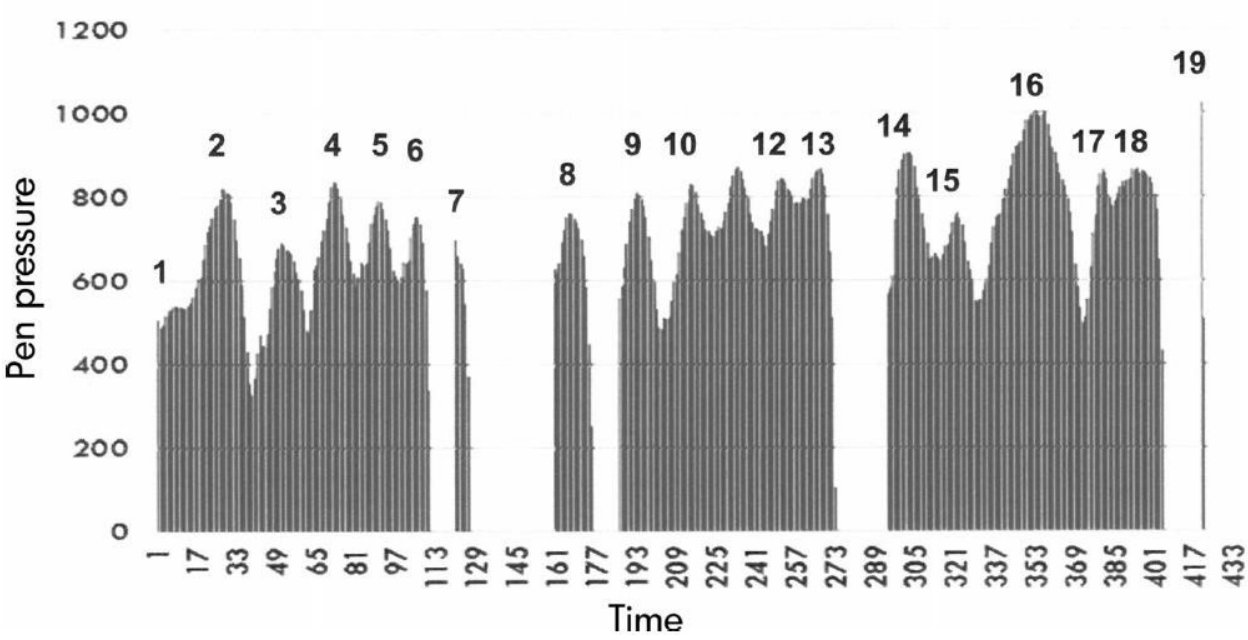

Figure-1: Graph of pen pressure versus time of a signature (numerals illustrates the relationship between the peaks and stroke segments) [1].

between genuine and simulated signatures. Stroke duration, velocity, and pen pressure were found to discriminate between genuine and simulated signatures regardless of the simulator's own style of signature or the style of signature being simulated. The results shows that the dynamic handwriting features, indicate that the style of the simulator's own signature and the style of signature being simulated can impact the characteristics of handwriting movements for simulations. Thus, the normal writing style of the simulator had a significant effect on the writing dynamics for the simulated signatures. Writer style characteristics might therefore need to be taken into consideration as potentially significant when evaluating signature features with a view to forming opinions regarding authenticity [10].

Developing A Prototype for Pen Pressure Patterns

Through this experiment a prototype was derived using simple mathematical treatment of the pen pressure data recorded by a digital pen movement recording device. Pearson's correlation coefficient was used to compare the data of the pen pressure patterns. The prototype could be used as a complementary technique to improve the objectivity of signature examination and also has a good potential to be developed as a tool for automated signature identification. In addition, the establishment of the relationship between the stroke segments and peaks in the pressure patterns graph allows the

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comparison of signatures with variation in structures. In this study, the treatment of the pen pressure data using Pearson's correlation coefficient provides an objective means to determine the degree of matching between two signatures, which could be used for the identification and elimination of common authorship [1].

Hidden Signature method

Hidden Signature method describe a proposition for replacing the template signatures with the hidden signature—an artificial signature which is created by minimizing the mean misalignment between itself and the signatures from the enrollment set. The hidden signature opens a number of new possibilities for signature analysis. Statistical properties of the hidden signature were applied to normalize the error signal of the verified signature and to use the misalignment on the normalized errors as a verification basis. A satisfying error rates that allow creating an on-line system, ready for operating in a real-world environment is achieved.
Dynamic time warping (DTW) is used to form a misalignment score between the verified signature and a set of template signatures [2].

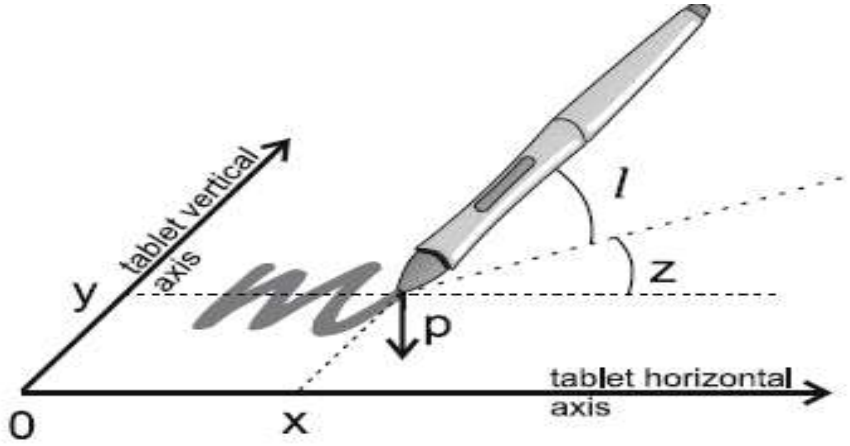

Figure-2: Signature on-line acquisition by Wacom Intuos (WACOM,2015) [2].

Slant and Size Transformation method

In this method a theory was tested that on-line adaptations to the rescaling of visual feedback are better described by the neuromotor noise theory of Van Gemmert and Van Galen than by traditional chronometric approaches. According to this processing demand that is reflected in deteriorated signal-to noise ratios (SNRs) in the neuromotor system is equivalent to a change in scaling factor of slant or size. At the behavioural level, deteriorated SNRs will result in less fluent writing, which can be compensated by applying a biomechanical noise- filtering strategy of increased limb stiffness. This strategy will lead to increased axial pen force, and, with higher degrees of difficulty, to a loss of movement speed. Results revealed decrements in writing fluency together with increments in axial pen force and increments in movement time when compensations to the feedback transformations coincided with the more difficult task conditions. These findings

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contrast with the traditional resource theory (Kahneman, 1973) in which chronometric measures alone indicate increased processing demands [5].

Frictional Coefficient and Control of pen pressure

The study was aimed at using a computer simulation to show that the effects of sliding and static friction may be subtle but can significantly alter the dynamics of pen control. These simulations lead to hypotheses on human strategies which may reduce the disruptive effects of friction. Specifically, it is proposed that subtle modulations in the general level of normal force are necessary if the relative pen dynamics are to remain stable across changes in pen speed. Empirical data was collected from 11 adult subjects writing repetitions of a series of words in different script sizes, at different speeds and on different surfaces. Axial pen pressure was recorded in synchrony with x, y position information. The resulting pressure records are used to explore some hypotheses of previous researchers on pressure variability, as well as the hypotheses developed from the computer simulations. Finally a theoretical model is presented of a 'perceptual instrument' that may serve to explain the sensitivity apparent amongst competent writers in the modulation of pen pressure [7].

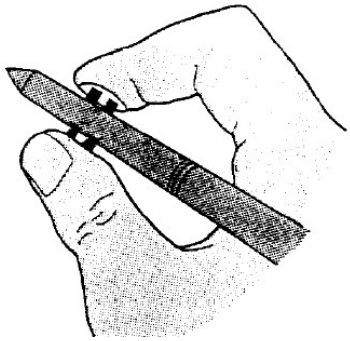

Figure-3: Control of pen - pressure(7)

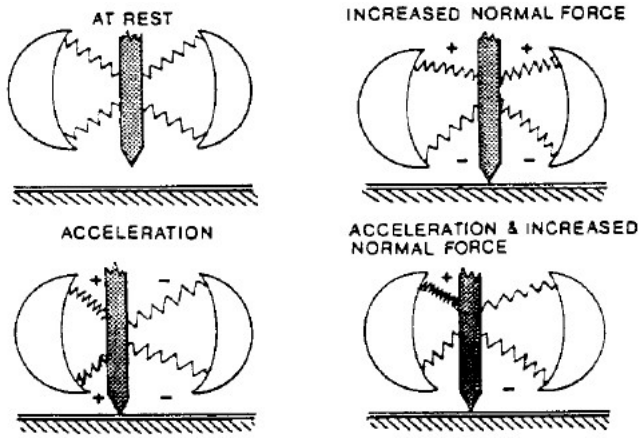

Figure-4: A model for perception of frictional effects [7].

Interval-valued symbolic features

It proposes a new method of representing online signatures by interval-valued symbolic features. Concept of writer-dependent threshold is exploited and the concept of feature-dependent threshold to achieve remarkable reduction in equal error rate is introduced. Extensive experimentations are conducted to evaluate the performance of the proposed methods by projecting features onto Eigenspace and Fisherspace. The results of the extensive experiments reveal that the proposed representation scheme is simple and efficient, has achieved a considerable reduction in EER, and thus outperforms several other contemporary models. In this research global features of online signatures are used to form an interval-valued feature vectors. Methods on symbolic representation are proposed for signature verification and recognition [8].

Vishvjit S. Nalwa, describe a robust, reliable, and elastic local-shape-based model for handwritten on-line curves. Biased and weighted harmonic mean is considered as a graceful mechanism or tool of combining errors from multiple models. A successfully tested signature verification algorithm is also described. This approach rely primarily on the detailed shape of a signature for its automatic verification and breaks the tradition of relying primarily on pen dynamics [6].
The usefulness of pen dynamics during on-line signature production in automatic on-line signature verification must be investigated. Such dynamics might include not only velocities and forces, but also the varying orientation of the pen, and the way in which a signer grasps a pen.

Correlation between Spectral Coherence and Time-domain

It helped to investigate the spectral coherence and time-domain correlation between pen pressure (axial pen force, APF) and several kinematic variables in drawing simple patterns and in writing cursive script. Findings show that overall coherence is low (< 0.5) and decreases with pattern complexity, attaining its lowest value in cursive script. Looking at subjects separately, it is found that only in a small minority of writers" biomechanical coupling" between force and displacement takes place in cursive handwriting, as indicated by moderate to high negative overall correlations. The majority of subjects displays low coherence and correlation between kinematics and APF. However, APF patterns in cursive script reveal a moderate to high replicatability, giving support to the notion of a" centrally" controlled pen pressure. A motor task demanding mechanical impedance control, such as handwriting, apparently introduces a complexity that is not easily explained in terms of a passive mass-spring model of skeleto-muscular movement [4].

Every individual has a unique handwriting characteristic. An examiner uses these unique characteristics to differentiate a forged document from a genuine. There are number of different methods discovered to measure pen pressure in handwriting verification. Different pen dynamics and handwriting features are used to differentiate between genuine and forged handwriting. In the following table shows combination of different techniques, computer software and statistical parameters used to examine pen pressure and other pen dynamics as a tool to

differentiate between genuine and forger handwriting/signature.

There is a great demand of on-line signature/handwriting verification systems in the commercial market. These automatic

Discussion

verification systems have the potential to replace the traditional verification systems done manually

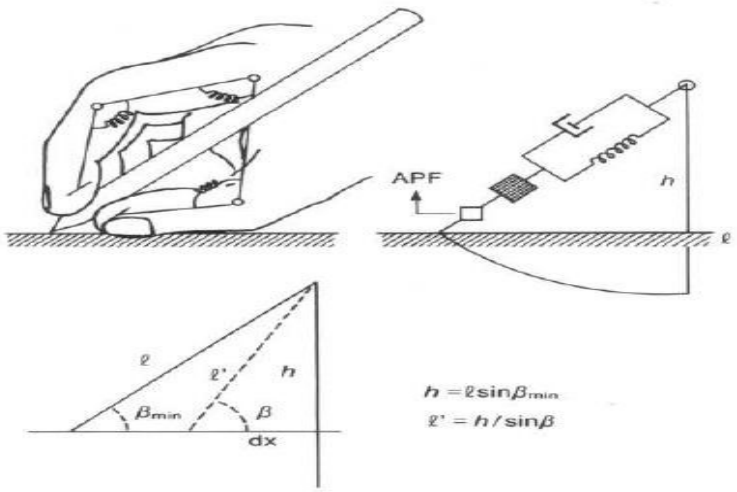

Figure-5: Biochemical model relating planar movement to axial pen pressure (h is fixed height of hinge, l is distance from hinge to pen tip, β is current pen angle, βmin is minimum angle for surface contact, dx is current distance between pen tip and the normal) [4].

PEN PRESSURE MEASURING METHODS			
S.No.	**BASIS**	**COMPUTER SOFTWARE USED**	**MODEL & STATISTICAL PARAMETERS**
1	Dynamic handwriting features	• Wacom Intuos 3 digitizer tablet • MovAlyzeR Version 4.1 • Wacom inking pen	• ANOVA • Tukey's HSD test
2	Slant and size transformations	• Calcomp 9000 digitizer tablet • VAX-workstation 310 software	ANOVA
3	Measure of frictional coefficient and control of pen pressure	• Quest Micropad pressure sensitive pad • Acorn BBC microcomputer • Pen with force transducer within barrel	Pearson correlation
4	Interval-valued symbolic features	• Digitizer tablet • digitizer pen	• Dynamic Time Warping(DYW) • Hidden Markov Model(HMM) • Support Vector Machine(SVM) • Neural Network • MCYT-Signature subcorpus database
5	Replacing Template signature with Hidden signature	WACOM, 2015 digitizer tablet	• Dynamic Time Warping(DYW) • Hidden Markov Model(HMM) • Support Vector Machine(SVM) • Neural Network • MCYT-online database
6	Digital biometric signature	• Wacom tablet LCD STU-520 • Namirial "Firma Grafocerta" software	
7	Spectral coherence & time-domain correlation between pen pressure & other kinematic variables	• Calcomp 9000 digitizer tablet • PDP 11/45 Computer • Digitizer pen • VAX Station 2000 computer • Fortran-77 software	• Spectral coherence • Fourier transform

8	Prototype using mathematical treatment of pen pressure patterns	• Wacom Intuos 4,5 Pro Inking pen • Wacom Intuos Pro medium digitizer tablet • MovAlyzeR version 6	Pearson correlation coefficient

Table-1: Different pen pressure measuring methods

Conclusion

In manual verification by a expert there are few drawbacks associated with human nature like tiredness and absent-mindedness which may influence the verification ability. In online verification by using a digitizer tablet and a pen to record samples pen pressure and pen dynamics are the mostly considered and examined to verify the samples. It was found that pen pressure which is an important individual characteristic of handwriting was found more in simulated samples or forgeries. The variations in pen pressure are usually manifested in the contrast of darkness and lightness of the ink stroke. However, the nature of the ink and the absorbance of the paper surface may hinder the examination. In addition, the pen pressure pattern of the entire writing could hardly been visualized by tradition photographic technique. This limitation of offline verification is overcome by online verification systems through which pen pressure pattern of the entire signature can be visualized and compared in a graphical form. Further investigation on the usefulness of pen during online signature production in automatic online signature verification must be done. Such dynamics might include not only velocities and forces, but also the varying orientation of the pen, and the way in which a signer grasps a pen. Pen pressure can be a useful parameter in discriminating between genuine signatures and forgeries. In order to advance the use of pen pressure and other pen dynamic features in the forensic environment there is a need to develop pressure measurement techniques.

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