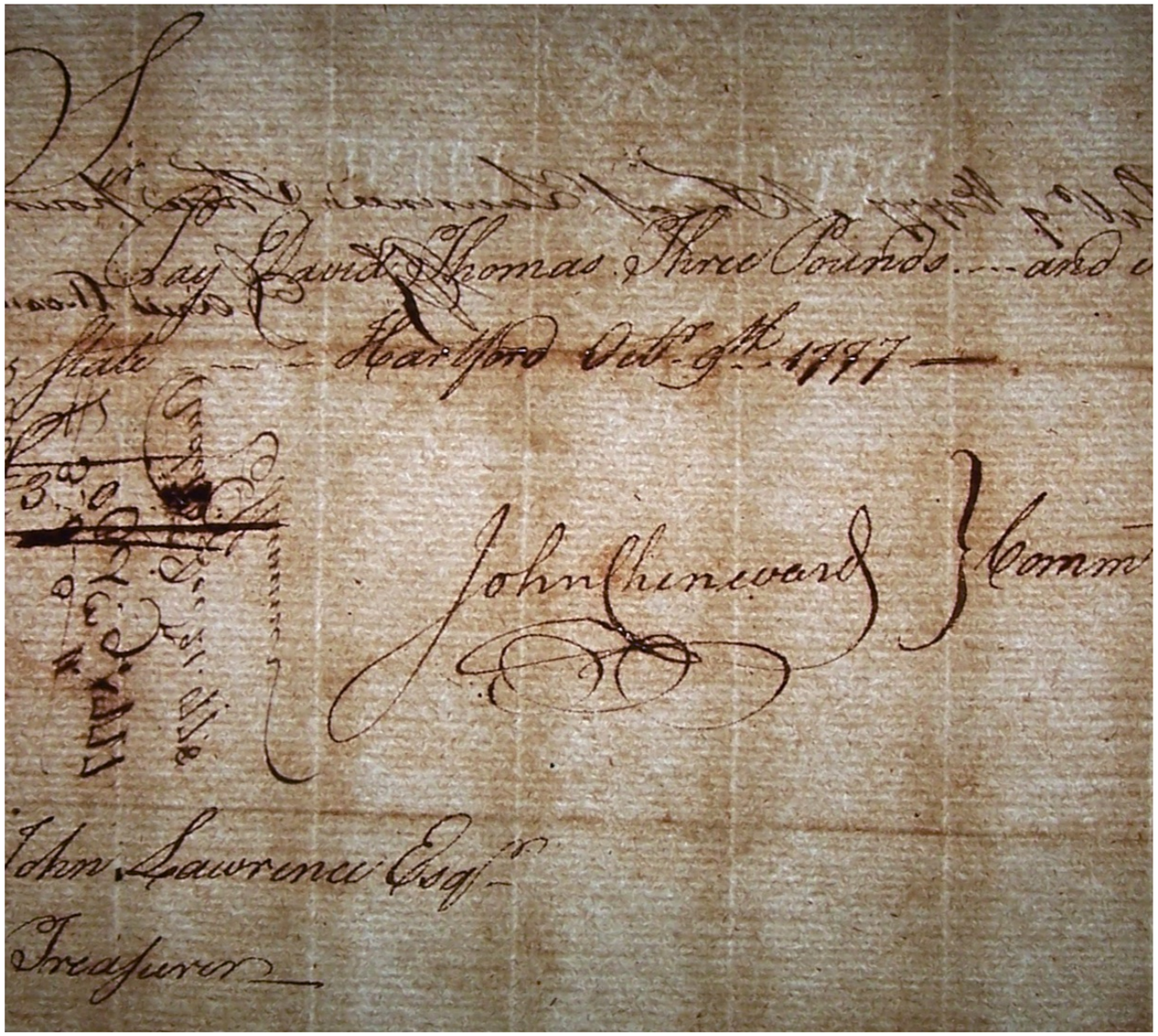
Chemistry of Invisible Inks



TEACHER GUIDE

Chemistry of Invisible Inks

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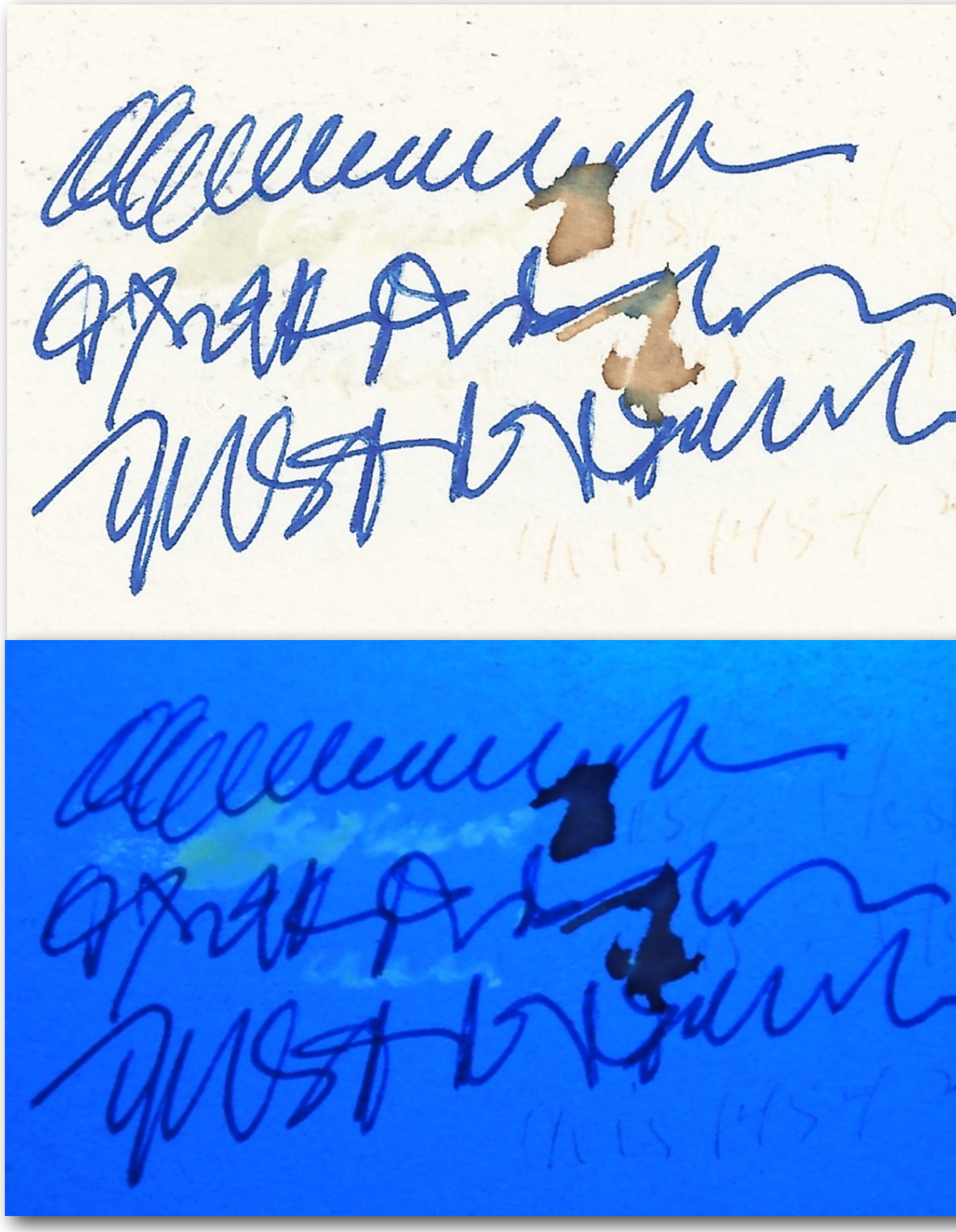


Materials

MATERIALS

1. Kit Materials
2. Local Materials
3. Safety

KIT MATERIALS

Quantity	Description
1	Package / 100, plain index cards (white; 3x5") ACTIVITY 1, ACTIVITY 2
50	Small cups, plastic ACTIVITY 1, ACTIVITY 2
10	Steel nib dipping pens ACTIVITY 1, ACTIVITY 2
1	Bottle, security ink[1] ACTIVITY 2
1	Black light / flashlight handheld ✦ ACTIVITY 1, ACTIVITY 2
10	Magnifiers ACTIVITY 1, ACTIVITY 2
1	Box, cotton swabs ACTIVITY 2

✦ Required 4 double-A batteries; not included

CD-ROM *Understanding the Chemistry of Invisible Inks*

ACTIVITY 1 *Investigating Organic Fluids as Invisible Inks*

ACTIVITY 2 *Investigating Chemical Reagents as Invisible Inks*

Teacher Guide

Student Guide

Glossary

Background Information: *Chemistry of Invisible Inks*

PowerPoint: *Chemistry of Invisible Inks* PPT and MOV

Folder: Engraving Images

- 1862 US Treasury seal
- Norwegian Banknote, 1778
- 1770 South Carolina Banknote

[1] The commercial invisible ink included in this kit has a volatile (combustible) vehicle component. Keep away from sparks and open flames.

LOCAL MATERIALS

Quantity	Description
	Dry iron ACTIVITY 1
	Kitchen towels (or similar) ACTIVITY 1
100 mL	Cabbage extract (170 g red cabbage) ACTIVITY 2
1	Bottle, ferric sulfate tablets (drug store) ACTIVITY 2
1	Bottle, white vinegar (grocery store) ACTIVITY 2
100 mL	Milk ACTIVITY 1 – INDEPENDENT INVESTIGATION
100 mL	Grapefruit juice ACTIVITY 1 – INDEPENDENT INVESTIGATION
100 mL	Orange juice (non-pulp) ACTIVITY 1 – INDEPENDENT INVESTIGATION
100 mL	Honey ACTIVITY 1 – INDEPENDENT INVESTIGATION
5g	Table sugar ACTIVITY 1 – INDEPENDENT INVESTIGATION
1	White onion ACTIVITY 1 – INDEPENDENT INVESTIGATION
1	Bottle, lemon juice (or juice from lemons) ACTIVITY 1
1	Box, baking Soda ($NaHCO_3$) (grocery store) ACTIVITY 2
1	Box, cornstarch (grocery store) ACTIVITY 2
1	Tide® detergent (grocery store) INDEPENDENT INVESTIGATION, ACTIVITY 2
1	Box, washing Soda (Na_2CO_3) (grocery store) ACTIVITY 2
1	Bottle, Betadine® (iodine solution) (drug store) ACTIVITY 2
1	Beaker, 1000 mL (or similar) ACTIVITY 1 – INDEPENDENT INVESTIGATION, ACTIVITY 2

LOCAL MATERIALS (CONT)

Quantity	Description
1	Beaker, 100mL (or similar) ACTIVITY 2
1	Kitchen knife ACTIVITY 1 – INDEPENDENT INVESTIGATION, ACTIVITY 2
1	Kitchen funnel ACTIVITY 2
10	Pencils (No. 2) ACTIVITY 1, ACTIVITY 2
10	Ballpoint pens ACTIVITY 2
1	Marking pen ACTIVITY 2
1	Bottle, rubbing alcohol (70% isopropyl alcohol) ACTIVITY 2
1	Coffee filter ACTIVITY 1
2	Table spoons (or mortar and pestle) ACTIVITY 2

Access to: Computers, tablets, or iPads with internet access *

* Useful but not absolutely necessary

SAFETY

Quantity	Description
10	eye goggles ACTIVITY 2

SECTION 2

STEM Correlation Information

Click HERE to review a correlation of this kit with the Next Generation Science Standards.

SKILL / CONCEPT

Experimental / Engineering Design
Investigating
Scientific Method
Measurement
Data Analysis
Communication
Technology

CONCEPT PRINCIPLES / KNOWLEDGE

- Chemical & Physical Processes
- Chemical Reactions
- Data analysis; constructing tables and graphs
- Fluorescence
- Light, Light Spectrum
- Optical Contrast
- Organic & Inorganic compounds
- Chemical Reaction Types
- pH, pH Indicators
- Reflectance / Transmittance

CONSOLIDATED STEM STANDARDS

S = National Science Education Standards (NSES) - K-4, 5-8, 9-12
T = International Technology & Engineering Educators Association (ITEA) - K-2, 3-5, 6-8, 9-12
A framework for K-12 Science Education: Practices, Crosscutting Concepts, and Core Ideas (NRC; 2011) - Draft
E = Accreditation Board for Engineering and Technology (ABET) - 11-12
A framework for K-12 Science Education: Practices, Crosscutting Concepts, and Core Ideas (NRC; 2011) - Draft
M = National Council of Teachers of Mathematics (NCTM) - PreK-2, 3-5, 6-8, 9-12 Consolidated STEM Standards

SCIENCE

A.1.2 Design and conduct scientific investigations.

A.1.3 Use technology and mathematics to improve investigations and communications.

A2.1 Conceptual principles and knowledge guide scientific inquiries.

A.2.3 Scientists rely on technology to enhance the gathering and manipulation of data. New techniques and tools provide new evidence to guide inquiry and new methods to gather data, thereby contributing to the advance of science. The accuracy and precision of the data, and therefore the quality of the exploration, depends on the technology used.

E.1.1 Identify a problem or design an opportunity.

E.1.2 Propose designs – choose alternative solutions.

E.1.3 Implement a proposed solution.

E.1.4 Evaluate a proposed solution.

TECHNOLOGY

2.A An identification of the criteria and constraints of a product or system.

8.H Begin the design process …

9.K Create a prototype to test a design concept.

11.O Refine the design.

11.P Evaluate the design solution.

11.R Communicate observations.

12.O Operate the system to validate the design.

ENGINEERING

ET 1 **(Designed World)** Study of designed systems, processes, materials, and products.

ET1.A **(Products, Processes, Systems)**

ET1.B **(Nature of Technology)**

ET1.C **(Using Tools and Materials)**

ET 2 **(Engineering Design)** Creative and iterative process for identifying and solving problems under constraints.

ET2.A **(Defining and Researching Technical Problems)**

ET2.B **(Generating and Evaluating Solutions)**

ET2.C **(Optimizing and making Tradeoffs)**

ET3 **(Technological Systems)** Effectively using technology systems.

ET3.A **(Identifying and Modeling Technological systems)**

ET3.C **(Control and Feedback)**

ET4 **(Interactions of technology & Society)** Decisions are affected by technology.

ET4.A **(Interactions of Technology & Society)**

ET4.B **(Interactions of Technology and Environment)**

ET4.C **(Analyzing issues involving Technology & Society)**

MATH

1.0 **Understand:** numbers, ways of representing numbers, relationships among numbers, and number systems.

2.0 **Algebra:** Understand numbers, ways of representing numbers, relationships among numbers, and number systems.

3.0 **Geometry:** Analyze characteristics and properties of two- and three-dimensional geometric shapes and develop mathematical arguments about geometric relationships.

4.0 **Measurement:** Understand measurable attributes of objects and the units, systems, and processes of measurement.

5.0 **Data Analysis & Probability:** Formulate questions that can be addressed with data and collect, organize, and display relevant data to answer them.

6.0 **Problem Solving:** Build new mathematical knowledge through problem solving.

7.0 **Recognize:** reasoning and proof as fundamental aspects of mathematics.

8.0 **Organize and consolidate:** their mathematical thinking through communication.

9.0 **Connections:** Understand how mathematical ideas interconnect and build on one another to produce a coherent whole.

10.0 **Create and use representations to:** organize, record, and communicate mathematical ideas.

SECTION 3

EXPERIMENTAL DESIGN CONSIDERATIONS

LAB OVERVIEW & LEARNING OBJECTIVES

In this guided, open investigation, students will investigate invisible inks from various recipe sources to create 'secret' documents as well as to determine the effectiveness and mode of action (chemical / physical process) for the invisible ink 'developer.'

- To *understand* the history of invisible inks and their use
- To c*ompound* (make) invisible inks from selected recipe sources
- To *determine* the mode of action (mechanism) of various chemical and physical processes
- To *understand* the difference between transmitted and reflected light
- To develop comparison criteria for evaluating the 'effectiveness' of an invisible ink:
  - contrast (against a background)
  - sharpness (line strokes not visible distorted)
  - stroke width (discernibility)
- To *recommend* the 'most effective' invisible ink / developer combination

EXPERIMENTAL DESIGN CONSIDERATIONS

These activities allow students to learn about physical and chemical processes, chemical reactions involved in creating and using invisible inks and their application in creating secret messages!

Suggested investigation order:

ACTIVITY 1 ***Investigating Organic Fluids as Invisible Inks***
(INTRODUCTORY to INTERMEDIATE)

Understanding how a natural material (lemon juice / organic acids and sugars) can be employed as an invisible ink and how the application of heat sets up a chemical reaction [oxidation (caramelization)] of organic materials (organic acids and sugars).

MODEL Investigation (30 minutes)
INDEPENDENT Investigation (45 minutes)

ACTIVITY 2 ***Investigating Chemical Reagents as Invisible Inks***
(INTERMEDIATE / ADVANCED)

Understanding how various chemical reagents (acids, bases, fluorescent compounds, inorganic salts, organic compounds) can be employed as an invisible inks and developers. Creating "secret messages" and security documents.

MODEL Investigation (30 minutes)
INDEPENDENT Investigations (30 minutes - up to 2 lab periods)

EXPERIMENTAL DESIGN CONSIDERATIONS

To help students effectively integrate the information they will be expected to apply in these investigations, they need to understand and discuss the following concepts before starting this lab activity. (See the Glossary files and power point The Chemistry of Invisible Inks.)

- Types chemical and physical processes
- Using heat as a “developer”
- Use of pH indicators as “developers”
- The process of caramelization
- Types of chemical reactions in developing invisible inks
- How an invisible ink is constructed
- What role paper plays in the success of an invisible ink
- The cursive line
- Light, the visible spectrum and fluorescence
- Reflected and transmitted lighting

MODEL EXPERIMENT

At one time or another, most students have created documents containing an ‘invisible ink’ to communicate information to a special recipient without allowing others to view it.

An invisible ink is any substance that can be used for writing (typically on a paper substrate) that is not easily detected by the naked eye under general lighting conditions. The process of rendering the ink visible – a color change - (ideally by the intended recipient) is known as developing the ink. The procedure or materials used in that purpose is the developer.

In the model experiment your students will use a steel nib dipping pen to create a various stroke lines (cursive and printing) on a piece of copy paper using lemon juice as the invisible ink. A pencil line will circle these ink strokes. This invisible ink document will then examined using reflected and transmitted light as well as being subjected to heat energy of a dry iron. An evaluation of the ink/developer combination will be made using three criteria: contrast, sharpness, and stroke width.

INDEPENDENT INQUIRY PATHS

After completing the model experiment, your students will be given suggested paths to take for their Independent Inquiry Investigations.

Scientific inquiry will help your students develop skills in communication, teamwork, critical thinking, and commitment to lifelong learning. This investigation can help foster these skills.

An important part of becoming a scientist is to learn to keep clear, concise, and accurate laboratory notes. At the conclusion of the independent investigations, you may choose to have students create mini-posters that showcase their investigational results or provide a formal report to you. Remind students that an organized lab notebook should demonstrate originality and reflection while serving as a record of their work.

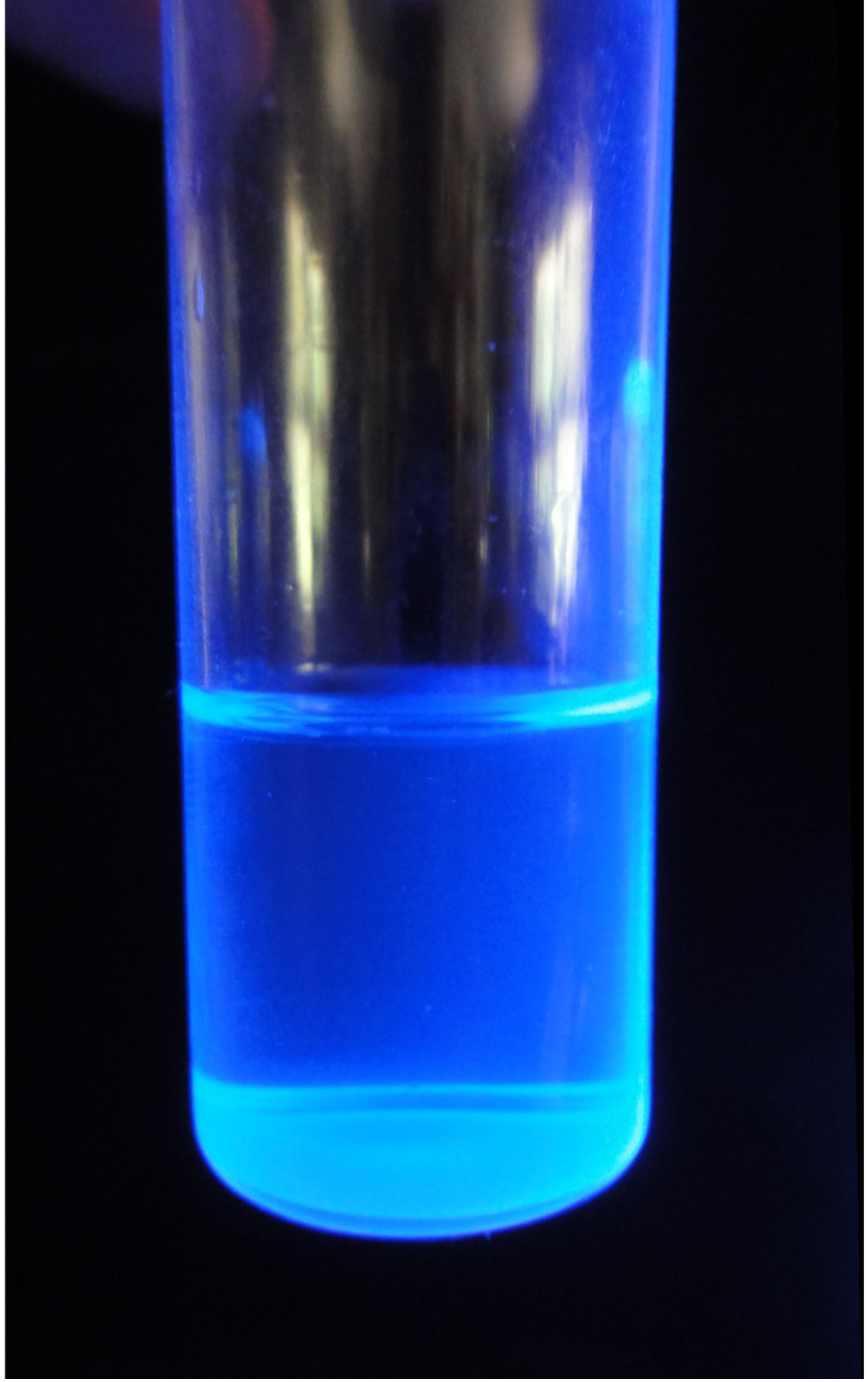
Section 4

Getting Ready ...

Getting Ready ...

Prior to beginning the model experiment, your students should read through or view the background information pdf as well as the power point presentation (*Chemistry of Invisible Inks*) to review and understand what invisible inks are; a brief history of their use, and some selected invisible ink recipes. Further, your students should read and understand the following terms: *chemical* and *physical processes*, *chemical reactions*, *oxidation*, *pH*, *fluorescence*, and *chemical precipitation*.

Students should refer to the *Glossary* (see PDF file on CD-ROM) as well as the PowerPoint *Chemistry of Invisible Inks*

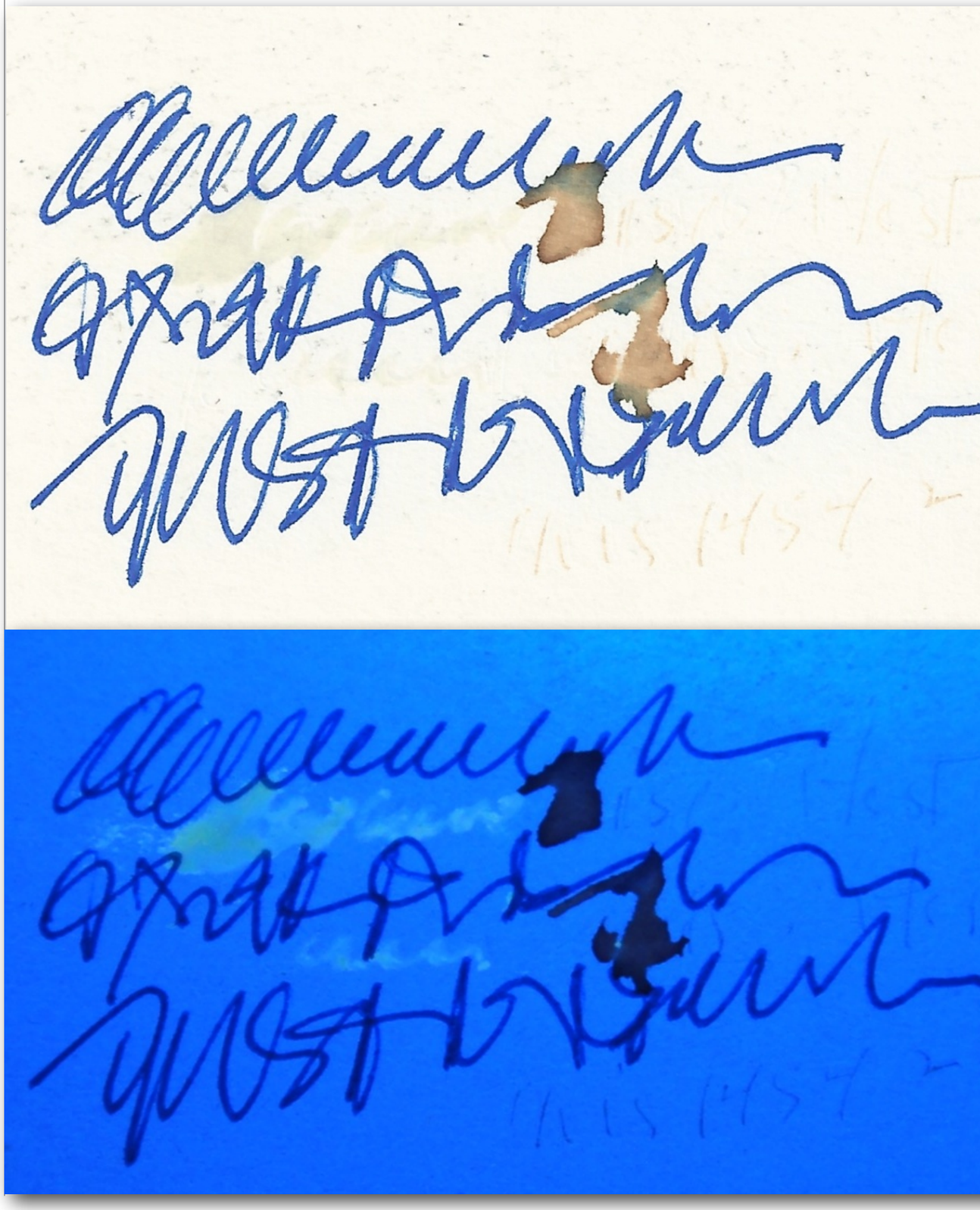


TEACHER GUIDE

Chemistry of Invisible Inks

ACTIVITY 1

The Model Investigation – *Investigating Organic Fluids as invisible Inks*



ACTIVITY 1

What You Need ...

WHAT YOU NEED ...

1. Kit Materials
2. Local Sourcing
3. Materials Per Class
4. Materials Per Group

WHAT YOU NEED ...

Kit Materials

Quantity	Description
10	Steel nib dipping pens
1	Black light / flashlight handheld
10	Small cups, plastic
10	Index cards, plain (white)
10	Magnifiers
	CD-ROM Understanding the Chemistry of Invisible Ink
	Provide students with either hard copy or digital files:
	Student Guide
	Glossary
	Background Information: Chemistry of Invisible Inks
	Chemistry of Invisible Inks PPT and MOV

Local Sourcing:

Quantity	Description
1	Dry iron
1	Kitchen towel (or similar)
1	Coffee filter paper (optional)
100 mL	Bottle, lemon juice (or juice from lemons[1]); 100mL
10	Pencils (No. 2)
100 mL	Milk (whole or cream) [INDEPENDENT INVESTIGATION]
100 mL	White onion [INDEPENDENT INVESTIGATION]
100 mL	Orange juice [INDEPENDENT INVESTIGATION]
100 mL	Grapefruit juice [INDEPENDENT INVESTIGATION]
100 mL	Honey [INDEPENDENT INVESTIGATION]
5 g	Table sugar [INDEPENDENT INVESTIGATION]

[1] If the juice from lemons is used, plan to use coffee filter paper (formed into a cone) to filter it.

Per Class

Quantity	Description
	Dry iron
	Kitchen towel (or similar)
1	Coffee filter paper (optional)
10	Index cards, plain (white)
10	Magnifiers
10	Steel nib dipping pens
1	Bottle, lemon juice (or juice from lemons)
10	Plastic cups, small
10	Pencils (No. 2)
	CD-ROM with Background Information and Power Point presentation
	Access to: Computers, tablets, or iPads with internet access * Portable device cameras / scanner (optional) *

Per Group

Quantity	Description
1	Plastic cup, small
1	Lemon slice (large) or 10 mL lemon juice (in the plastic cup)
1	Steel nib dipping pen
1	Magnifier
1	Index card, plain (white)
1	Pencil, No. 2
	Lab Notebook
	Access to: Computers, tablets, or iPads with internet access * Portable device cameras / scanner (optional) *

Pre-Lab Preparation ACTIVITY 1

PRE-LAB PREPARATION MATERIALS

- lemon juice (or squeezed lemon)
- 10 small plastic cups
- iron (ironing station)
- cloth towel
- 5 sheets 8x10-inch copy paper
- 10 steel nib pens
- 10 pencils
- 10 index cards (plain)

PRE-LAB PREPARATION

✓ Pour approximately 10mL concentrated lemon juice into ten small cups.

✓ Set up an "ironing station" – an iron and cloth towel that will serve as the ironing surface.

CAUTION! HOT SURFACE! *Remind students not to touch the iron! Continuously monitor the iron.*

✓ Cut 5 sheets of 8x10-inch copy paper in half (approx. 4 x 5-inch)

✓ Distribute the following to each student group (10):
- Steel nib dipping pen
- Small plastic cup with lemon juice
- Pencil
- Index card

✓ View the process of caramelization:

http://www.youtube.com/watch?feature=fvwp&v=CUKhrlklGB0&NR=1

You may wish to have students view this video clip as well.

What To Do ...

MODEL INVESTIGATION

In this model investigation, your students will use lemon juice as an invisible ink to create a document that will be examined using reflected / transmitted light and thermal (heat) imaging techniques.

WHAT TO DO ...

STEP 1

Have your students review the power point presentation (or movie) to make sure they are familiar with:

- ✓ Transmitted light
- ✓ Reflected light
- ✓ Chemical reaction termed *caramelization*

STEP 2

Have students create a data table in their laboratory notebook and record the major chemical constituents of fresh lemon juice:

DATA TABLE MAJOR CHEMICAL CONSTITUENTS OF LEMON JUICE	
Vitamins (ascorbic acid)	45-6- mg/100mL
Sugars (fructose / glucose)	21.6 percent (by volume)
Inorganic acids (citric acid)	4.8g / 100g

TEACHER NOTE: Application of consistent heat is important to oxidize the inorganic acids / sugars in the lemon juice.

STEP 3

Ask students, of these major lemon juice ingredients, which (if any) do they suppose would play a role in invisible ink and its development?

Student answers will vary but should include:

- acid solutions are colorless materials that can react with paper fibers making them visible under certain lighting conditions (e.g. transmitted light)

- sugar solutions are colorless materials and can react with heat (process of caramelization) turning a darker (amber) color

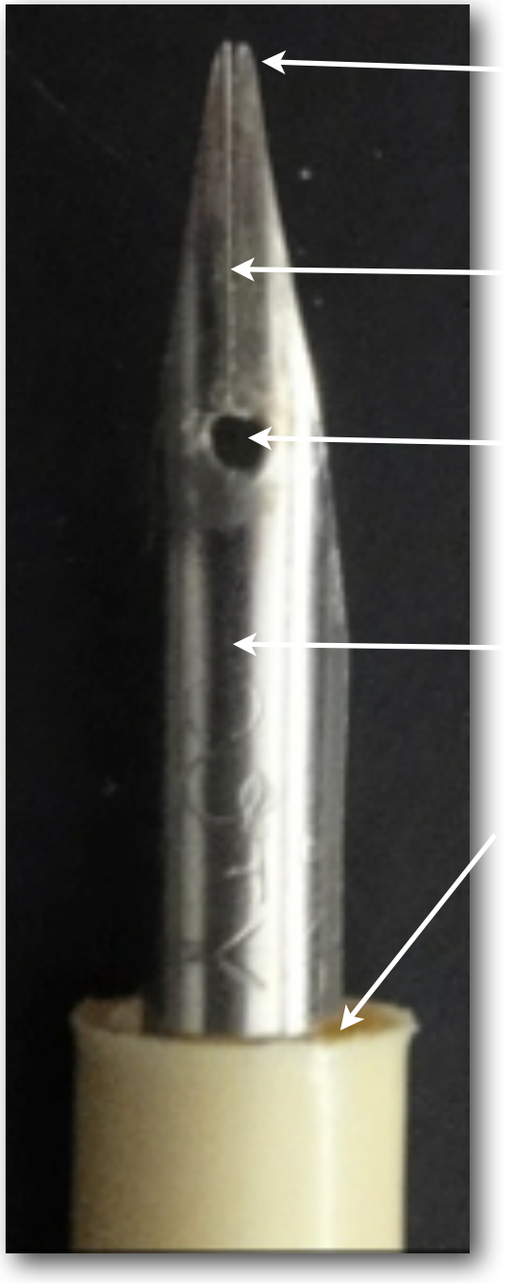
STEP 4

Understand the anatomy of a nib.

Remind students that dipping the nib into the writing liquid (up to the vent hole) is needed to collect and store ink for writing. Remind them to try not to dip the nib too deep into the ink (half way to the vent hole) because too much ink can be deposited. Too much ink will run off onto the paper causing a large ink puddle!

STEP 5

Have students carefully dip the tip of their nib into the lemon juice in the small cup.



NIB ANATOMY

Tip: (iridium, or tipping material) hard surface metal that contacts the paper and delivers a measured amount of ink.

Slit: The space in which ink travels down to the paper by means of capillary attraction.

Vent Hole: provides the space for air to travel back into the pen to replace the ink that is consumed in writing.

Body: Sectioned and truncate cone; provides the shape and rigidity to hold the tines in position.

Base: Thinnest part of the nib, fits into the tubular section and is held in place by the feed. (The section is the part of the pen that joins the feed and nib to the barrel).

TEACHER NOTE: Concentrated lemon juice (e.g. Real lemon® brand) has a low viscosity (as compared to regular writing inks) and as such can easily run off the nib onto the paper. Caution students to dip the nib into the juice just halfway to the vent hole and allow excess lemon juice to run off the nib by "tapping" it against the cup wall.

STEP 6

Direct students to make a series of strokes on the index card using the lemon juice as invisible ink. Have them make these marks with something known to their group – e.g. a name followed by a series of numbers or hatch marks. Make these marks at least ¼ to ½-inch in height. Use a pencil to circle these marks. Have each group record their name in pencil on the upper right area of the paper. Have students record this "intended message" in the data table in their laboratory notebook.

STEP 7

Allow the index card paper to thoroughly dry. Have student groups pass their index card document to another group to develop and decipher it.

STEP 8

Have the receiving student group examine the index card document using reflected and transmitted light. Have students first shine the light from the handheld flashlight onto the index card paper. Ask students if any marks or strokes be observed?

Next, have students position the document between their eye and the handheld flashlight (shine light through the document). Can any markings be observed? Have students record their observations in the data table of their laboratory notebook.

As you direct, have students use a portable camera device, or a computer scanner, to capture an image of the circled area on the document. Later, They should take another image after heat development. (These images can be included in reports and shared with other groups.)

STEP 9

To heat-develop index card documents, have students place the index card document on top of a folded cloth and apply a heating iron to the paper - "ironing" over the circled area. Remind students not to rest the iron on the paper, keep it moving! After about 15-60 seconds of applied heat, can any latent writing (invisible ink line strokes) be observed?

SAFETY: Never leave a plugged in iron unattended!

TEACHER NOTE: Application of consistent heat (from a heating iron) is important to oxidize the inorganic acids / sugars in the lemon juice.

STEP 10

Have students write a summary of the developing mechanisms in imaging document marks:

Developing Mechanisms:

Reflected Light (prior to heating)

Pencil marks reflect visible light (visible)
Lemon juice marks do not reflect visible light (invisible)

Transmitted Light (prior to heating)

Pencil marks (visible)
Lemon juice (visible – lighter area(s) but colorless)

Reflected Light (after heating)

Pencil marks reflect light and (visible)
Lemon juice marks visible (light amber / brown color)

Transmitted Light (after heating)

Pencil marks (visible)
Lemon juice marks visible (light amber / brown color)

STEP 11

Have students decipher the message and record it in the "recovered" section in a Data Table in their laboratory notebook.
Wash your hands before leaving the laboratory.

DATA ANALYSIS

Write an explanation of why a particular developing mechanism imaged document marks:

Reflected Light (prior to heating) 1

Pencil marks on paper fibers reflect visible light
Lemon juice marks on paper fibers do not reflect visible light - therefore are "invisible"

Transmitted Light (prior to heating) 2

Pencil marks on paper fibers reflect visible light

A heavy application of lemon juice on paper fibers (visible – lighter area(s) but colorless) [circle]. The acid in the lemon juice alters the paper fibers allowing them to have enhanced contrast – appearing lighter than the surrounding paper.