Lighting Up a Crime Scene: Fluorescence in Forensics

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This curriculum unit is recommended for:
11^{th} and 12^{th} grade Honors or Advanced Forensic Science

Keywords: fluorescence, photoluminescence, chemiluminescence, luminol, evidence, latent, ninhydrin, silver nitrate, fingerprints, blood detection

Teaching Standards: See Appendix 1 for teaching standards addressed in this unit.

Synopsis: This unit examines the importance of fluorescence to forensic science for latent evidence detection and analysis. It starts with a review of the dual theory of light and the electromagnetic spectrum. The use of visible light for the detection of evidence is discussed as well as its' use in the analysis of substances. Microscopy is explored through a lab activity. Light emissions are looked at with a focus on photoluminescence and chemiluminescence. These processes are studied before turning to their forensic applications. The unit presents several hands-on activities exploring fluorescence including a fingerprinting lab that uses ninhydrin and silver nitrate development as well as fluorescent powders and ultraviolet light to visualize latent evidence. A Luminol lab is presented where students are able to work with simulated blood, Luminol and bleach to discover the role of fluorescence in blood detection at crime scenes. A Color Lab is suggested for students to experiment with different substances they are likely to find at a crime scene by using different wavelengths of light, color filters and goggles to optimize the appearance of latent evidence.

I plan to teach this unit during the coming year to 120 students in Honors Forensic Science.

Lighting Up a Crime Scene: Fluorescence in Forensics

Jackie Smith

Introduction

“When am I ever going to use this in real life?” Any trigonometry, physics or chemistry teacher will tell you they have heard that lament from a student at some point in their career. Forensic Science is the answer to that question. With the plethora of true and fictional crime shows on television, most students have a passing familiarity with modern forensic science. Many of them will tell you they love Forensic Files or CSI. At the same time, many of those same students will tell you they are not “science” people. However, if you put a wall of blood spatter in front of them with a dead body on the floor, they will work diligently to figure out where the killer was standing or what position the victim was in when they were attacked. They will use trigonometry and physics to answer those questions, but they will be engaged and enjoying what they are doing.

Rationale

The most important aspect of forensic science is to be able to find evidence at a crime scene. Without this, there is nothing else – no arrest of a suspect, no trial with proof of wrongdoing, and ultimately, no justice. Sometimes at a crime scene, evidence will be obvious. A broken window, a body on a bed, or a muddy tire print are all examples of forensic evidence that are readily visible to crime scene investigators (CSIs). However, there may be a world of evidence at a crime scene not visible to the naked eye. Latent evidence detection at crime scenes is one of the most fundamental and yet challenging aspects of a crime scene investigator’s job. Fingerprints, blood, gunshot residue, bruises and bone fragments are just a few of the types of evidence found at crime scenes that may not be visible to the naked eye and which require special handling to locate and document.

Locating evidence at a crime is just the first task in the justice process. Next, the evidence must be observed and analyzed for all possible clues as to what happened and who may have been involved. Many types of latent evidence exhibit a property called fluorescence. Fluorescence is the emission of light due to the relaxation of an excited electron from an excited singlet state to the ground state.[1] The electron can become excited by the addition of energy in the form of light, a chemical reaction or by other means. The use of light to excite electrons which then fluoresce is called photoluminescence. An example of this process is a glow-in-the-dark toy that is held up to a light bulb for a few seconds and then, when the lights are turned off, emits an eerie glow that delights the user. The use of a chemical reaction to transfer energy to the electrons resulting in fluorescence is called chemiluminescence. Glow sticks contain chemicals called diphenyl oxalate and hydrogen peroxide that mix when the stick is bent. This reaction forms an unstable product that further decomposes to carbon dioxide, releasing energy. That energy is absorbed by electrons in the molecules of dye contained in the stick which causes them to become excited, jump to a higher energy level and then fall back to their original energy level releasing a photons of light in the process. That light is fluorescence.

This unit will look first at the nature of light and then at the structure of molecules and what gives them their fluorescent properties. It will then focus on the use of fluorescence to locate and analyze latent evidence at crime scenes. This unit nurtures students' interest in forensics while developing their lab skills. It also promotes critical thinking and problem solving skills while encouraging communication and teamwork.

Demographics

William Amos Hough High School is a large suburban high school of over 2500 students located in the small town of Cornelius, North Carolina just north of Charlotte. We opened our doors in 2010 to serve the northern part of the Charlotte-Mecklenburg School District. Eighty-four percent of our graduates go on to either two- or four-year colleges while 16% join the military. Twenty-one percent of our students are minorities and 13.2% are free or reduced lunch students.[2] We have a student-teacher ratio of 19.9 to 1. We offer a comprehensive college preparatory program in the arts and sciences. Classes are taught at the Standard and Honors levels and we offer 26 Advanced Placement courses in conjunction with the College Board. Our students consistently score well above the averages in our school district and our state on the end-of-grade tests in Biology, English II, Math I and Math III.[3]

Students are required to take Biology, an earth science and a physical science such as physics or chemistry. They may further explore their interest in the sciences through electives. We offer Honors Forensic Science and Honors Advanced Forensic Science to meet that need. With the overwhelming popularity of forensics in pop culture, these courses grab students' interest while teaching them valuable lab skills and critical thinking. The first-level course covers many of the basic areas of forensics such as crime scene processing, DNA analysis, blood spatter analysis, fingerprint analysis and toxicology. The second-level course builds on some of the basic materials but extends them further and includes new topics such as Forensic Botany, Accident Reconstruction, Counterfeiting and Art Forgery. Honors Forensic Science is a pre-requisite for Advanced Forensic Science. Forensic Science brings biology, physics, chemistry, earth science, math, civics, history and writing together in one class that answers the question "When am I ever going to use this in real life?"!

This curriculum unit is geared toward the first-year Honors class and will look at the difficulties of locating and documenting some types of biological and physical evidence at crime scenes. It will focus on the use of fluorescence to visualize otherwise invisible evidence.

Unit Goals

This unit is called "Fluorescence in Forensics." Course standards for this unit require that students be able to explain the Dual Theory of Light and the Electromagnetic Spectrum. Students need to understand that light interacts with matter in a variety of ways with an emphasis on luminescence. Students need to understand luminescence with a focus on photoluminescence and chemiluminescence. Students need to understand how this information is relevant to forensic science. They will practice microscopy. They will study what types of latent evidence can be visualized with different light sources and examine different materials for their fluorescent properties. Finally, students should be able to use various luminescence-based techniques to visualize different types of evidence and then to document the evidence sufficiently well so that it is admissible in court. This will include the development of fingerprints and the search for blood evidence and other biological fluids at a crime scene.

Content Research

Light plays a role in forensics in a variety of ways. First, evidence must be located. Regular visible light or specialty light sources such as black (UV) lights, infrared lights and colored filters fulfill this purpose. Once evidence has been located, it must be observed and have hypotheses formed about it. Finally, the evidence must be analyzed so that conclusions can be drawn. Light offers a range of testing options from microscopes to spectrometry. However, before students can understand how to visualize and analyze evidence, they need to understand what light is and how it interacts with matter. Once they have mastered these concepts, they can explore how light's interactions with different types of matter can be used to identify, document and analyze an evidence sample.

Electromagnetic Spectrum

Visible light is one small part of the electromagnetic spectrum (EMS). The EMS is all known forms of electromagnetic radiation arranged by wavelength.[4] For forensic purposes, the most important parts of the EMS are visible light, infrared radiation and ultraviolet radiation. These different forms of electromagnetic radiation have characteristic properties such as visibility/invisibility, wavelength, color and frequency.[5]

Figure 1. The Electromagnetic Spectrum Relevant to Forensic Science

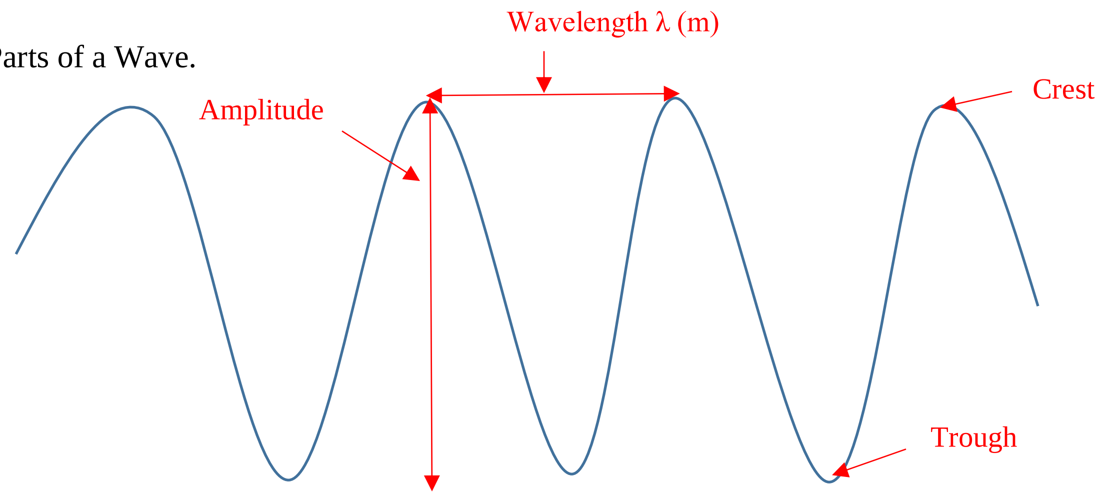
Ultraviolet		Visible Spectrum (nm)						Infrared
190-290	290-400	400-430	430-490	490-575	575-590	590-620	620-700	>700
Short wave UV	Long wave UV	Violet	Blue	Green	Yellow	Orange	Red	IR

→ Increasing Wavelength/Decreasing Frequency

← Increasing Energy

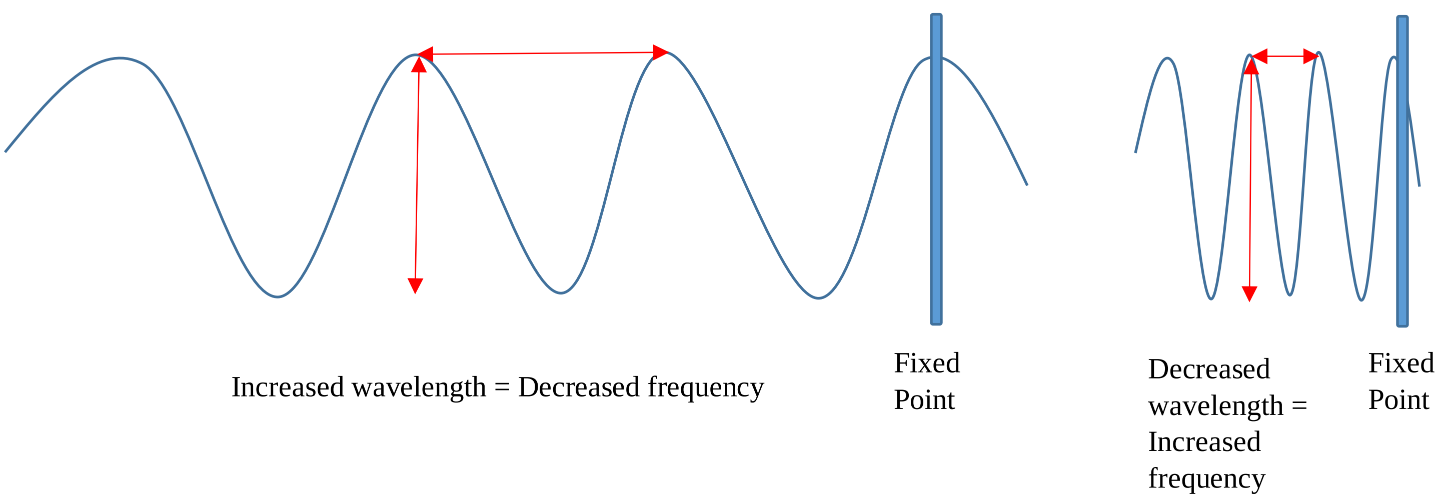
All light travels in waves. A wave is simply the movement of energy. The figure below illustrates the different parts of a wave.

Figure 2. Parts of a Wave.



The distance between the same spot on two successive waves is called the wavelength λ and is measured in meters.[6] Waves travel at different speeds in different media. The speed of a light wave, c, in a vacuum is approximately $3.0\text{x}10^8$ m/s.[7] The frequency of a wave, ν, is the number of waves that pass a given point in a unit of time.[8] For example, at the beach, ocean waves may pass a pier at the rate of 40 waves per minute. The metric unit of frequency is cycles (number of waves) per second or the hertz (Hz). Waves with longer wavelengths will have lower frequencies because it takes them longer to pass the given point.

Figure 3. Frequency of a Wave.



Frequency is inversely proportional to wavelength. Wavelength, wave speed and frequency are related by the formula $c = \lambda\nu$, where c is the speed of the wave, λ is the wavelength and ν is the frequency.[9] The amplitude of a wave is the height of the wave from the trough to the crest. The amplitude is a measure of the energy of the wave. Notice in Figure 3 although the wavelength changes quite a bit, the amplitude, or energy, of the wave does not change at all. Amplitude is independent of changes to wavelength, speed or frequency.[10]

While light travels like a wave, it also acts like a particle in the way it transfers energy to electrons. Every element has a defining number of electrons that are held in specific orbitals. Electrons are paired with each other in those orbitals with each electron in a pair having an opposite spin. This is known as the ground state and is the element's lowest energy state. Electrons gain energy through one of several mechanisms.[11] As these electrons gain energy, they move to a higher energy level. This is called the excited singlet state. When they lose energy, the electron drops back down to its original orbital and the lost energy is released as a photon of light. Different elements emit this light at different energy levels causing each element to have its own unique emission spectrum. Below is an image of the atomic emission spectrum of the element hydrogen.

Figure 4. Atomic Emission Spectrum of Hydrogen.

Image in the Public Domain.

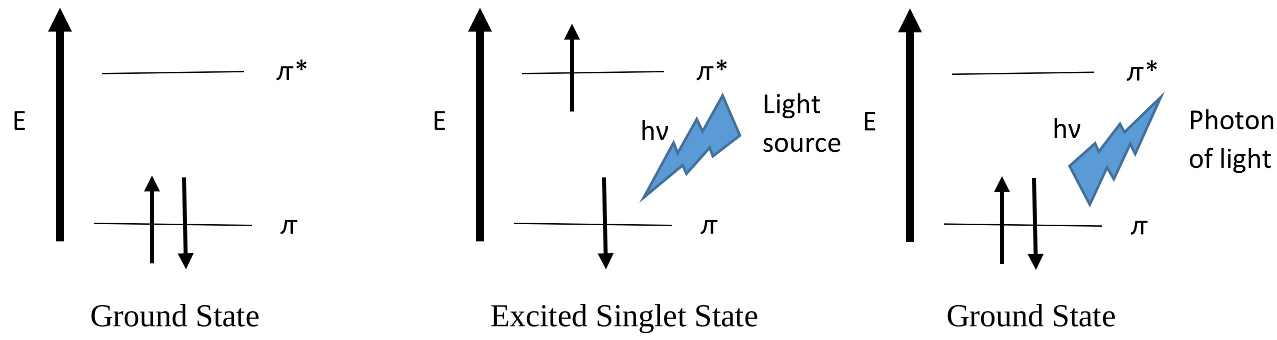
Light Emissions

There are two main classifications of light emissions – hot (*incandescence)* and cold (*luminescence)*.[12] Incandescence is the light produced when heat causes an object to emit energy to its surroundings as a broad continuous spectrum of visible and invisible radiation. An example would be a fire or an incandescent light bulb. Luminescence is the emission of a specific narrow range of discrete wavelengths that results when an electron in an excited state of a molecule or material relaxes to a lower energy state. An example would be a glow stick.

There are several types of luminescence classified by how the electron is initially excited. Chemiluminescence is light produced as the result of a chemical reaction, such as a glow stick or luminol reacting with blood.[13] Bioluminescence is light produced as the result of a biochemical reaction such as the glow of a firefly.[14] Electroluminescence is light produced by the addition of electricity to a molecule to excite an electron.[15] In photoluminescence, the electron is excited by exposure to a light source.[16] Photoluminescence can be broken up into two groups: fluorescence and phosphorescence.[17]

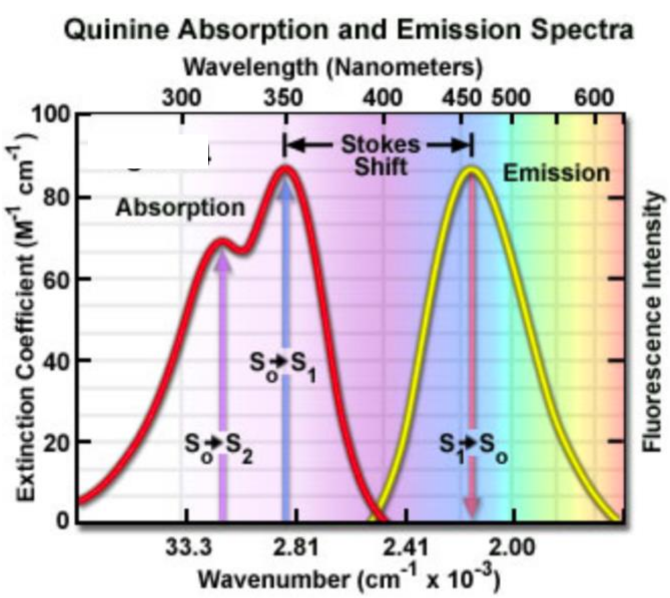
Fluorescence is the emission of light that occurs when electrons absorb shorter wavelength light, get excited, jump to a higher energy level and then emit light as they leave the higher energy level to return to their ground state.[18] The diagram below shows the action of the electrons and photons in the interaction. In the original ground state, two electrons with opposite spins occupy a pi (π) bond. A light source excites the electrons and one of the pair moves to a higher energy level denoted by π*. The electron then loses the additional energy it gained from the light source and drops back down to its original state while a photon of light is released.

Figure 5. Action of Electrons and Photons in Photoluminescence.[19]



The emission of light happens almost immediately. The emitted light will always be of a longer wavelength than the excitation light. This is called the Stokes shift.[20] Notice in the graph below that shows the absorption and emission spectra of quinine, a fluorescent substance, the difference between the wavelengths of absorption (320-350 nm) and the longer wavelength of emission (450 nm) of the photon.

Figure 6. Quinine Absorption and Emission Spectra.



Credit: www.chem.uci.edu

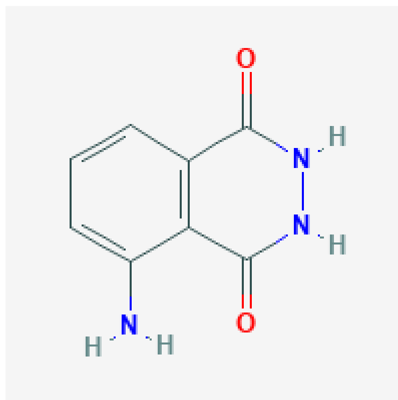
Objects that phosphoresce also absorb lower wavelength radiation but they retain the excited electron for much longer. Electrons drop back to their original state after much more time has passed which results in the longer wavelength light being visible for much longer.

Molecules in Forensics

Fluorescence occurs in solid, liquid or gas chemical systems.[21] The basis of fluorescence is found in the structure of the molecule at hand. When a molecule does fluoresce, the intensity of the emission is determined by the molecular structure and the chemical environment.[22] As mentioned before, fluorescence occurs when the molecule relaxes to its ground state after being excited in some manner. The specific frequencies of excitation and emission are different for each molecule or atom.[23]

Molecules are just different combinations of elements arranged in some way that is relatively stable. The various elements are held together by chemical bonds, single, double or triple. Below is the chemical structure of Luminol, $C_8H_7N_3O_2$, a chemical frequently used in forensics to detect the presence of bodily fluids at a crime scene. As you can see from its formula, it is made of 8 carbon atoms, 7 hydrogen atoms, 3 nitrogen atoms and 2 oxygen atoms.

Figure 7. Chemical Structure of Luminol.



Credit: National Center for Biotechnology Information (2020). PubChem Compound Summary for CID 10638, Luminol. Retrieved October 19, 2020 from https://pubchem.ncbi.nlm.nih.gov/compound/Luminol.

Below is an image of Luminol being used at a crime scene. Clearly something happened in this bathroom!

Figure 8. Luminol Glowing at a Crime Scene.

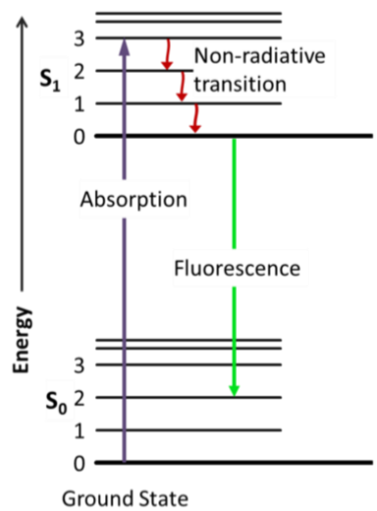
Image in Public Domain.

Everywhere two lines meet and there is not an element listed, there is the element carbon. Luminol is a double ring structure with double bonds between most carbon-carbon connections. It is the electrons in these bonds that absorb energy to move to a higher energy level and then fall back down, creating fluorescence. The actual reaction that takes place is characterized by the equation:

$$C_8H_7N_3O_2 + 2\ OH^{1-} \rightarrow C_8H_5NO_2 + 2\ H_2O + N_2$$

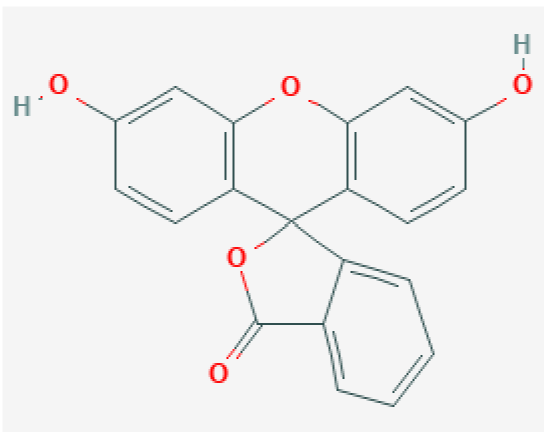
The following Jablonski energy diagram illustrates what is happening in the process. The purple arrow shows the absorption of energy and the excitation of the electron to the next highest energy level. The red arrows represent the vibrational relaxation of the molecule to the lowest level of the excited state, which does not radiate light. Finally, the green arrow represents the electron's drop in energy as it returns to the ground state and gives off a photon of light in the process.

Figure 9. Jablonski diagram representing fluorescence.



Below is the chemical structure of fluorescein, another molecule used extensively in forensics. It is used to create a glowing reaction in the presence of hemoglobin, a component of blood. It is also added to radiator fluid and can be used to help recreate the mechanics of a vehicle accident.

Figure 10. Chemical Structure of Fluorescein.



Credit: National Center for Biotechnology Information. "PubChem Compound Summary for CID 16850, Fluorescein" PubChem, https://pubchem.ncbi.nlm.nih.gov/compound/Fluorescein. Accessed 19 October, 2020.

Notice that this molecule is just made up of carbon, oxygen and hydrogen atoms. Many of the atoms are in rings with double bonds between the carbon atoms just as in Luminol. This structure contributes to its fluorescent properties.

Figure 11. Fluorescein under normal room light (left) and illuminated with an ultraviolet light.

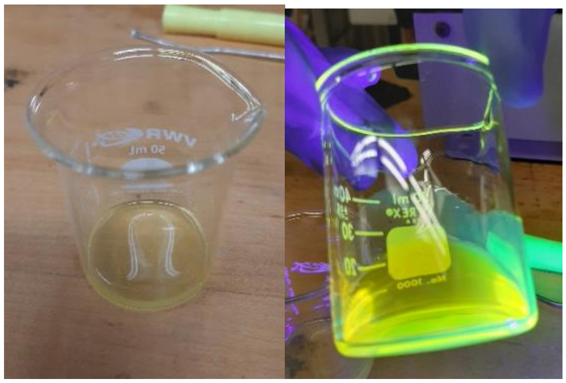


Photo Credit: Jackie Smith

Forensic Use of Light

The properties of light and the substances it interacts with are used to locate, observe and analyze evidence at crime scenes. The wavelengths of light most useful to forensics are visible, ultraviolet, infrared. To obtain these wavelengths at a crime scene, investigators use alternative light sources (ALS). Use of ALS at crime scenes enhances visualization of evidence by using fluorescence, absorption and oblique lighting techniques.

ALS can be used to detect latent fingerprints, body fluids, hairs and fibers, bruises, bite marks and wound patterns, variations in ink on documents, gunshot and explosives residue, human bone fragments, teeth, tire tracks, shoe prints, narcotics and many more kinds of trace evidence at crime scenes.[24] Each type of evidence has a wavelength of light at which it is most visible.

Table 1. Wavelengths of Light to Use for Maximum Visualization of Different Types of Evidence.[25]

Type of Evidence	**Wavelength of Light to Search With**	**Color of Goggles to Wear**
Shoeprints	White (oblique angle)	Clear
Bone or teeth	455	Yellow/Orange
Saliva	UV	Clear/Yellow
Ninhydrin	555	Clear
Untreated blood	415	Clear/Yellow
Fresh bruise	445	Yellow
Older bruise	535/555/575	Red

Visible light is used at all crime scenes to locate evidence. Crime scene technicians carry powerful white lights in their kits to use in locating this evidence. Obvious examples of visible evidence at a crime scene are a body, bullet casings, and broken glass. Visible light applied to a surface at an oblique angle will help visualize a footprint on a dusty floor and other less immediately obvious evidence.

Visible light is also used in the analysis of many types of evidence. Simply using a dissecting light microscope to examine a fingerprint or a bullet casing is one way light aids in forensic investigations. Determining the refractive index of an unknown substance by measuring the amount that light bends in a substance or observing the color change in a flame test are ways of using visible light to analyze and identify unknown substances. For example, as discussed above, each element emits characteristic wavelengths of light. When burned, boron emits a bright green color, while strontium emits a beautiful scarlet shade. Below is an example of a flame test that can be used to tentatively identify compounds.

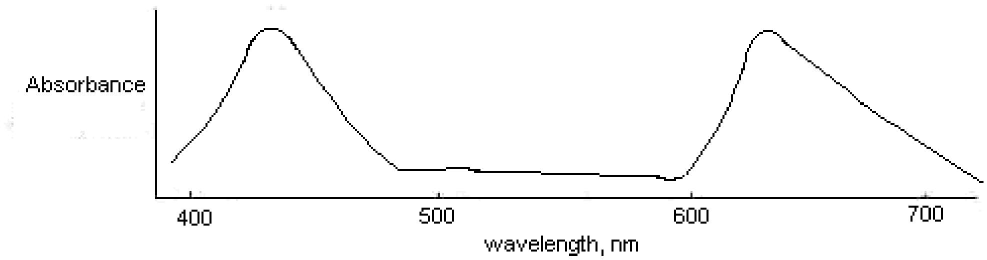
Figure 12. Atomic Emission Test.

From left, boron, sodium chloride, zinc chloride and strontium.
Photo by Jackie Smith

Magnification uses visible light. Magnifying lenses help detectives find trace evidence such as hairs and fibers. Stereomicroscopes are used to view and analyze that evidence on a macro scale. On a microscopic scale, compound microscopes are used to observe and analyze evidence. There are more types of microscopes than are within the scope of this paper to discuss but a few of the ones most commonly used in forensic applications include the bright field microscope, fluorescence and IR/UV microscopes and immersion microscopes.

Spectroscopy is another use of light that plays a major role in forensic science. Spectrophotometry uses light in the visible range to characterize substances. Many high school science departments have a UV/Vis Spectrometer, which shoots individual wavelengths of light through an object to determine the percent of light transmitted or absorbed at each wavelength. The resulting graph of the wavelength and absorbance data is known as the material's absorption spectrum. Each material has its own unique absorbance spectrum.

Figure 13. Absorbance Spectrum of Green Kool-Aid.



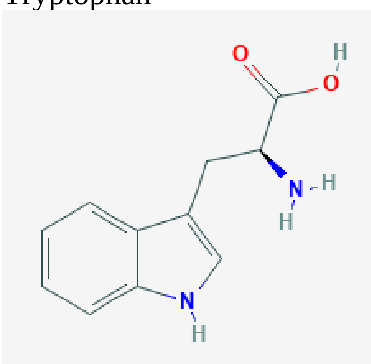
The Kool-Aid tested here absorbed light in the blue (400-500 nm) and red (600-700 nm) ranges while it reflected most light in the 500-600 nm range, which is green light. Thus, the Kool-Aid is green.

There are also spectrometers that use infrared light to analyze materials. Raman spectroscopy uses a laser on a substance and measures the pattern of light scattering that results. A portable version of one type of spectrometer is the Breathalyzer used by police on the side of the road to check for drunk drivers.

The visible evidence, however, is usually just the tip of the iceberg. The most common form of evidence at a crime scene is latent evidence. Examples include fingerprints, hairs and fibers, bloodstains that have been cleaned up, and gunshot residue. These types of evidence are much more difficult to see with the naked eye and require special handling to locate and collect them.

The most common light reactions used in forensics are chemiluminescence and photoluminescence. In chemiluminescence, a substance such as blood reacts with a reagent such as Luminol to emit light. Fingerprint detection can use chemical reactions with ninhydrin and iodine to visualize latent fingerprints at a crime scene. Fluorescent fingerprint powders can be used to dust for hard to see fingerprints and when the print is observed under a UV light, the ridge details stand out and it is more easily lifted and analyzed. Fluorescence spectroscopy is a quick, non-destructive way to locate saliva at a crime scene, which becomes particularly important in cases of sexual assault and homicide. Many times bite marks left on skin are not helpful in determining a perpetrator's dentition, but locating and testing saliva can lead to DNA matching to a suspect. Saliva has an enzyme called α-amylase which contains the amino acid tryptophan. Tryptophan fluoresces strongly at 350 nm when excited with 254 nm light.[26] Notice the similarities in tryptophan's molecular structure with the other fluorescent molecules discussed.

Figure 14. Molecular Structure of Tryptophan



Credit: National Center for Biotechnology Information. "PubChem Compound Summary for CID 6305, Tryptophan" PubChem, https://pubchem.ncbi.nlm.nih.gov/compound/Tryptophan. Accessed 4 November, 2020.

Ultraviolet light is the best way to visualize fluorescence at crime scenes. Since many biological fluids such as saliva, semen, and sweat fluoresce under ultraviolet light, it is possible to visualize and record these types of evidence using forensic light sources and appropriate cameras and filters. Fingerprints on difficult to print surfaces are also greatly enhanced by the use of fluorescent fingerprint powder and a UV light with a filter for viewing.

Fluorescence plays other roles in forensic science besides just the location of evidence at crime scenes. Photoluminescence can be used in the lab to age bone fragments. Researchers have discovered that cross-sections of bone that are less than 30 years old exhibit statistically significant more fluorescence than bones that are older than 30 years.[27] This helps to narrow down whether anthropologists are dealing with an historical find or a forensically relevant recent criminal action. Some researchers have used fluorescence spectroscopy at a crime scene to detect the presence of dried saliva on inanimate objects such as a drinking glass.[28] This efficiently narrows down areas needed to be tested for DNA samples and results in the best possible samples for DNA analysis being selected at the crime scene.

Instructional Implementation

Forensics lends itself well to many types of instructional activities. Brief lectures with guided notes will be used to introduce the main concepts to students. There will be interactive warm-ups and spot assessments included to check for student understanding and to reinforce learning. There will be several activities to communicate background information as well. Students will conduct a simple fluorescence lab to see how fluorescence can be induced in different materials. There will be a flame test demonstration to show students how light can be used to analyze and identify materials. Once they have mastered the basics, students will move on to more hands-on activities. Students will conduct fingerprint development labs exploiting chemical reactions by using ninhydrin and silver nitrate to visualize latent prints. Students will also conduct a fluorescent fingerprint powder lab where they will use ultraviolet light to enhance latent fingerprints. Students will work with Luminol to search for blood that has been cleaned up from a mock crime scene. Students will conduct a color lab where they will explore the fluorescence of various substances that might be found at a crime scene with different types of light, filters and goggles to determine the optimum combination for visualizing different types of evidence.

Day 1

Today will be an introduction to light and its uses in forensics. There will be notes with a PowerPoint presentation (see Appendix 2) that take students through the basics of light as a wave and light as a particle. We will discuss the emission spectra of various substances and how electrons gaining and then losing energy contribute to them. We will then discuss the two types of light emissions including the many forms of luminescence. We will define fluorescence in terms of the energy levels of electrons and look at how and why substances always emit light of a longer wavelength than they absorbed.

Day 2

We will begin today's class with the "Turning on the Light" fluorescence activity to introduce students to how the different types of fluorescence can be induced. (See Appendix 3) Then, we will look at some special molecules in forensics like Luminol and fluorescein and talk about their structures and the properties imparted to these molecules by their structures. As part of this discussion, we will conduct one of the Luminol demonstrations. (See Appendix 4)

Day 3

Today we will discuss the use of alternative light sources in forensics to locate and examine evidence. We will talk about infrared, visible and ultraviolet light as well as demonstrate fluorescence, absorbance and oblique lighting techniques. We will discuss the different wavelengths of light that are better for different types of evidence along with which colored filters best visualize the evidence. We will conduct the Fluorescent Fingerprints lab today. (See Appendix 5)

Day 4

On this day, we will discuss the use of light to analyze evidence to determine its composition and identity. We will begin with a simple microscope lab to make sure students are proficient in the use of a compound microscope. (See Appendix 6) We will then conduct the flame test lab to allow students to attempt to identify substances by the colors of light they emit. (See Appendix 7)

Day 5

Today students will put together everything they have learned about light and fluorescence to experiment with various substances, colored filters and light sources to determine which combination of filter and light type is best for visualizing different types of evidence. Students will then be given one of several "Crime Boards" and asked to identify latent evidence using the techniques they have learned in this unit. (See Appendix 8)

Appendix 1. Teaching Standards

HFS-FUL-1 Students will understand the properties of light.

- HFS-FUL-1a Students will be able to explain the Dual Theory of Light.
- HFS-FUL-1b Students will be able to explain the electromagnetic spectrum.

Understanding the basic properties of light is essential to an understanding how to use light in a forensic setting to visualize latent evidence.

HFS-FUL-2 Students will be able to describe how light interacts with matter including absorbance, reflection, refraction and transmission.

The way light and matter interact is the basis of how light is used in forensic investigations. Absorbance and reflection are the basis of all color observations. Each material has a characteristic refractive index by which it can be identified.

HFS-FUL-3 Students will be able to explain the emission of light from matter as a result of luminescence.

- HFS-FUL-3a Students will be able to distinguish between the different types of luminescence based on how the electrons are excited.
- HFS-FUL-3b Students will be able to explain how fluorescence works.

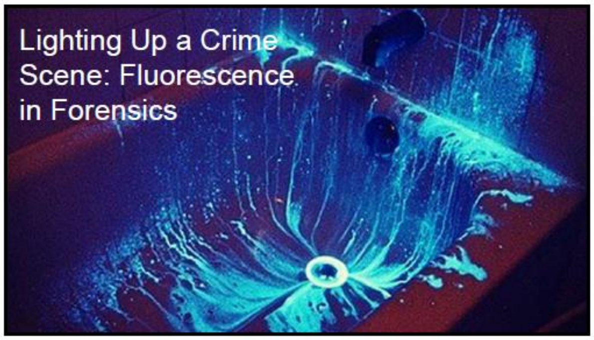
Students will understand the differences between chemiluminescence and photoluminescence in terms of how they are induced. Students will be able to explain what happens on an atomic level when electrons are excited by a chemical reaction or by a light source.

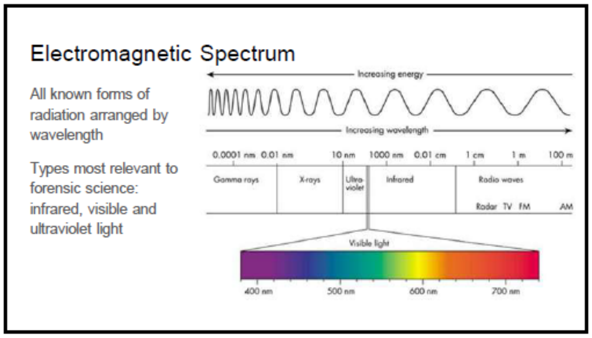
HFS-FUL-4 Students will understand how the properties of light are used in a forensic setting to locate, document and analyze evidence.

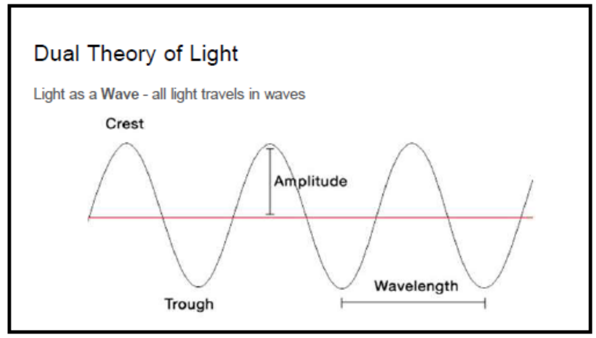
- HFS-FUL-4a Students will be proficient in using a compound light microscope.
- HFS-FUL-4c Students will be able to develop fingerprints using ninhydrin and silver nitrate techniques.
- HFS-FUL-4d Students will be able to use fluorescent fingerprint powder to develop latent fingerprints at a crime scene.
- HFS-FUL-4e Students will be able to use Luminol to detect blood at a crime scene.

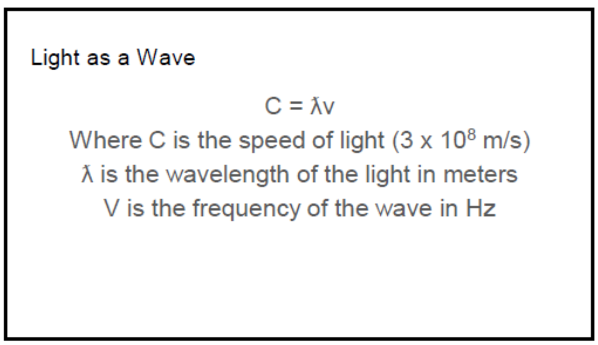
Students should be able to synthesize all of the material from this unit to become proficient in the use of light techniques, particularly fluorescence, in a forensic setting.

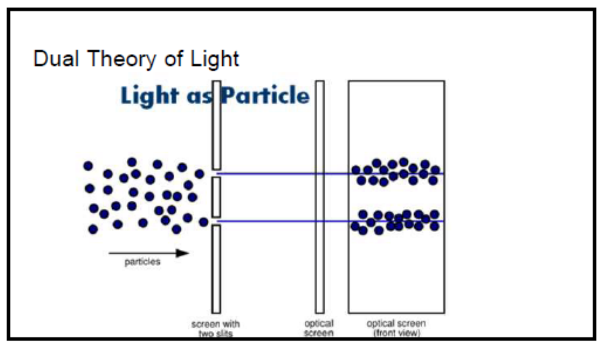
Appendix 2. Powerpoint Presentation



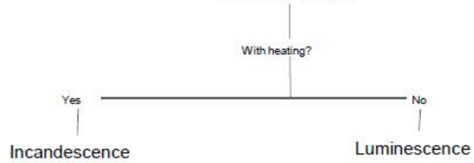








Emission of Light



Light Emissions

Hot - incandescence: light produced when heat causes an object to emit energy as broad spectrum of visible and invisible radiation

Ex. fire, light bulb

Light Emissions

Cold - luminescence: emission of a specific narrow range of wavelengths that results when an e^- in excited state drops back to ground state

Ex. glow stick

Types of Luminescence

Depends on how the electron is excited:

- Chemiluminescence - excited by chemical reaction
  - Ex. glow sticks
- Bioluminescence - excited by biochemical reaction in body
  - Ex. firefly
- Electroluminescence - excited by electricity
  - Ex. glow wire
- Photoluminescence - excited by light
  - Ex. glow-in-the-dark toy
- Triboluminescence - excited by mechanical forces
  - Ex. Wint-o-green life savers

Lab

Turning On the Light Activity

Types of Photoluminescence

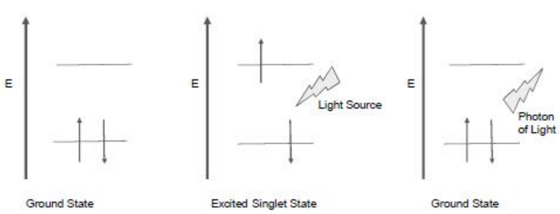
Fluorescence:

Emission of light that occurs when an electron absorbs light, jumps to a higher energy level and then emits a photon of light as it falls back to its original energy level.

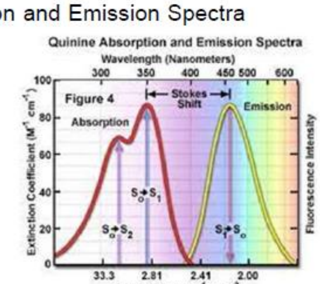
Phosphorescence:

Same as fluorescence except that molecule retains the excited electron for a lot longer before dropping back to ground state so glow lasts longer.

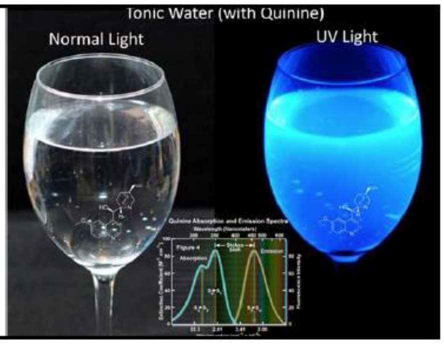
What is Fluorescence?



Absorption and Emission Spectra



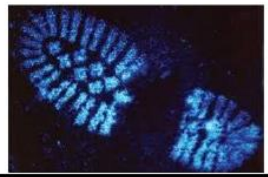
Example: Quinine



Fluorescence

Luminol oxidizes in basic conditions:

$$C_8H_7N_3O_2 + 2\ OH^{1-} \rightarrow C_8H_5NO_2 + 2\ H_2O + N_2$$



Luminol Demo

Forensic Use of Light

Light used to: locate, observe and analyze evidence

Most useful: infrared, visible and ultraviolet light

Get these by using ALS - Alternative Light Source

ALS uses fluorescence, absorption and oblique lighting techniques

Types of Evidence

Type of Evidence	Wavelength of Light to Search with	Color of Goggles to wear (or filter to use)
Shoe prints	White (oblique)	clear
Bone or teeth	455 nm	yellow/orange
saliva	UV	clear/yellow
Untreated blood	415	clear/yellow
ninhydrin	555	clear

Visible Light

Used at crime scene to locate evidence

Can use oblique technique to find footprints, fingerprints, etc…

Used in lab to analyze evidence - stereoscopes and compound light microscopes, refractive index, flames test

Microscope Lab

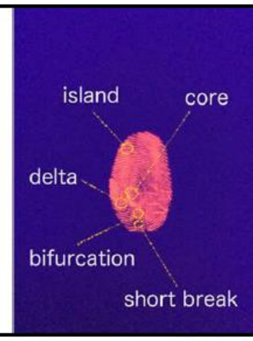
Flame Test Lab

UV Light

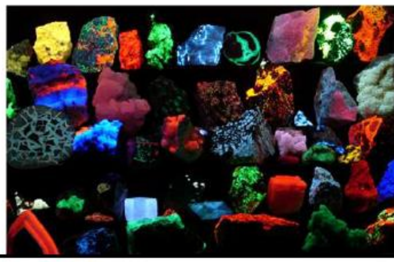
Used to detect things like body fluids - saliva, semen, blood

Used to analyze things like fingerprints with fluorescent powders

Fingerprint Lab



Color Lab



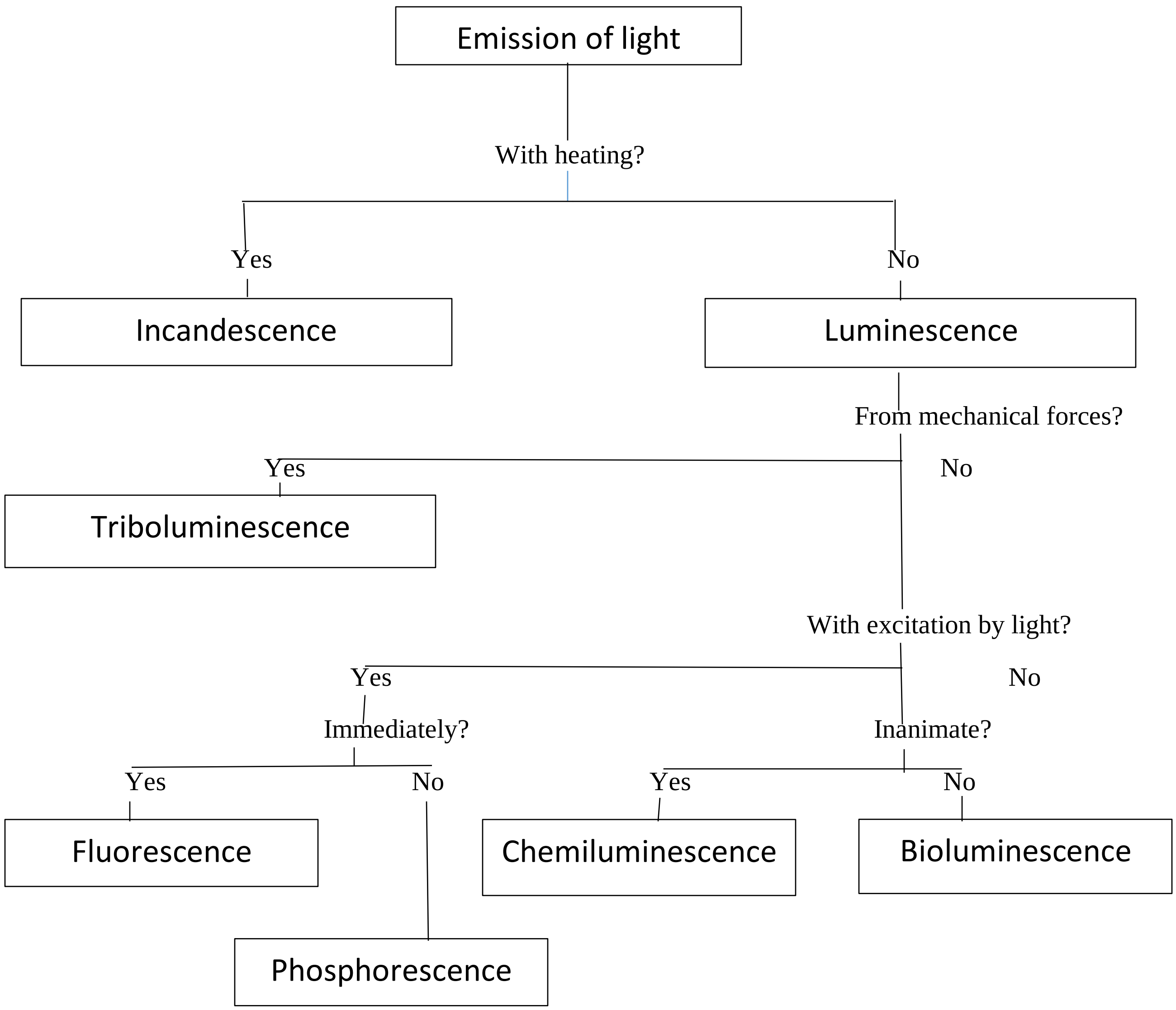
Appendix 3 Activity – Turning On The Light
(Adapted from JCE Classroom Activity: #68 Student Activity Turning on the Light)

Name: ____ Date: ___________ Block: _______

Turning on the Light Activity

Objective: Demonstrate the various types of luminescence using a variety of materials.

Background: The following diagram outlines the types of light emissions by the way energy is added to excite the electrons.



Materials: Several spinach leaves	knife
70% isopropyl alcohol	cutting surface
Spoon	wintergreen Lifesaver
Beaker	pliers

Test tube	plastic baggie
Test tube holder	UV flashlight
Lamp with incandescent bulb	piece of fluorite
Graduated cylinder	

Various markers, crayons, paints, stickers, toys, cloth, papers, tonic water

Procedure:

1. Chop 2-3 spinach leaves with the knife on a cutting surface. When chopped very finely, place in small beaker.
2. Add 30 ml of 70% isopropyl alcohol to the spinach and mix thoroughly with the spoon.
3. Fill a test tube with this chlorophyll solution.
4. Obtain several of the following items: markers, crayons, stickers, toys, cloth papers, tonic water, and fluorite.
5. In a darkened room, expose each item to a lighted incandescent bulb (lamp) for approximately 15 seconds. Observe and record the color and intensity of any light emitted from each item in the data chart below.
6. Turn off the white light. In the darkened room, observe and record the color and intensity of any light emitted from each item.
7. In the darkened room, expose each item to the UV flashlight. BE SURE YOU ARE WEARING THE ORANGE GOGGLES FOR THIS PART! Observe and record the color and intensity of any light emitted from each item.
8. Turn off the UV light. Observe and record the color and intensity of any light emitted from each item.
9. Obtain a Wintergreen Lifesaver, a plastic baggie and a pair of pliers.
10. Place the lifesaver in the baggie.
11. Hold the lifesaver with the pliers and in a darkened room crush the lifesaver. Observe and record any light emitted from the lifesaver as it is crushed. NOTE: You must be watching the candy get crushed closely.
12. Using the flowchart above, label in the data table each of the items you observed as luminescent or non-luminescent. In the next column, label each luminescent item as fluorescent, phosphorescent, triboluminescent.

Data Table

Item	**White Light ON**	**White Light OFF**	**UV Light ON**	**UV Light OFF**	**Luminescent or not?**	**Type of Luminescence**
Chlorophyll Solution						
Fluorite						
Lifesaver						

Analysis:

1. Explain why you labeled each of the items the way you did in the last column of the data table.

2. How are fluorescence, phosphorescence and triboluminescence similar? How are they different?

3. Why do white light and UV light interact differently with the same materials?

4. If you observed light when crushing the wintergreen lifesaver, what is the source of energy for this light?

KEY – Activity Turning on the Light

Analysis

1. Items that emit light without heat are luminescent. Fluorescent items include the chlorophyll solution, the fluorite, tonic water, fluorescent markers/papers/stickers. Phosphorescent items are usually labeled “glow-in-the-dark” and may include toys and art items. Wintergreen lifesavers are triboluminescent.
2. All three are processes in which light is emitted from a substance without heat. They differ in the way the substance is excited. When light is used to excite an electron in a substance, and the sample emits light immediately, we call the process fluorescence. Phosphorescence also involves using a light to excite a substance, but there is a delay before light is emitted and the emission lasts longer. Triboluminescence appears in a substance excited by the mechanical action of breaking or striking.
3. White light and UV light are each associated with different wavelengths and energies of light.
4. The source of energy is whatever does the crushing. It is a transfer of energy from your hand to the pliers (crushing the candy) into light energy.

Appendix 4. Luminol Demo/Lab

The purpose of this demonstration is to show students how Luminol reacts with hemoglobin in the blood to fluoresce, making it much easier to find at a crime scene, as well as how blood can be found even after a criminal has cleaned up a crime scene with bleach.

Luminol powder can be purchased from most scientific supply companies. It needs to be mixed fresh each day you will use it, as the prepared solution does not have a long shelf life. You will need either simulated blood from a scientific supply company or animal blood from the butcher shop, prepared Luminol in a spray bottle, bleach and plenty of paper towels. You will also need to find an area that can be made absolutely dark. My science prep room works well for this and I bring the students in a few at a time.

To prepare this demonstration, I like to first take some blood on a paper towel and write a word such as "murder" on the floor. I then blot up the visible blood. Bring students to the area and ask them to see if they can find any blood. Then turn out the lights and spray the area with the blood with the Luminol solution. You should see your word glow a light blue color. Turn on the lights and ask the students if they think they can clean up the blood and not get caught for this murder. Give them a chance to wipe the floor with bleach. Then turn the lights back off and watch the area with the bleach light up! It is a neat effect to take a paper towel with bleach on it and wipe it back and forth on the floor with the lights out.

If you don't want to work with animal or simulated blood, you can perform the following demonstration to show the students what a Luminol reaction looks like.

1. For Solution A, dissolve 0.05 g of Luminol in 100 mL of 1 M NaOH.
2. For Solution B, mix 9 mL of bleach into 91 mL distilled water.
3. Chill both solutions in an ice bath until cool.
4. Darken the room and slowly pour the two solutions together. You should see a blue glow. When the lights are turned back on, the solution will appear yellow-green.

Appendix 5. Fluorescence in Fingerprinting Lab

NOTE: Most materials in this lab are skin and eye irritants. In addition, some will stain the skin. Gloves and goggles must be worn at all times while preparing for and conducting this lab.

Teacher directions to prepare the necessary solutions for this lab:

A. Ninhydrin. You can purchase from a scientific supply company such as Carolina Biologicals already in solution in a spray bottle or can or you can purchase ninhydrin powder and make your own solution. Dissolve 5 g of ninhydrin powder in 95 ml of acetone or alcohol and mix well. Dispense in a spray bottle.
B. Silver Nitrate. Dissolve 1 g $AgNO_3$ in 100 ml of water. Store in the dark.
C. Fixer Solution. Add 20 g sodium thiosulfate (hypo) plus 14 g sodium bisulfite to 100 ml of water and mix well.
D. Zinc Chloride. Add 3 g of $ZnCl_2$, 25 ml ethyl alcohol and 5 ml acetic acid to 70 ml of water.
E. Starch Solution. Add 2 g of cornstarch to 100 ml cold water. Bring to a boil while stirring. Cool before using.

Part 1: Ninhydrin

Purpose: The purpose of this lab is to use chemical reactions to visually enhance a fingerprint so that it can be analyzed and identified.

Materials:
4"x4" white paper slips
Ninhydrin solution in a spray bottle
Zinc Chloride solution
Gloves
Goggles
Heat gun
Dark box
UV light source

Precautions: Ninhydrin will stain skin and clothing. Zinc Chloride is a skin irritant. Goggles, gloves and aprons should be worn while performing this lab. Ninhydrin should be used in a fume hood or outdoors.

Procedure:

1. Place several fingerprints on a 4"x4" piece of white paper.
2. Tape up your print paper on the paper on the wall.
3. Spray your paper with the ninhydrin solution until the paper is covered.
4. Wait 24 hours for the print to develop or warm the paper gently with a heat gun.
5. Identify and mark at least 5 ridge characteristics on the print.
6. Dip your ninhydrin prints in the zinc chloride solution. This should turn the print orange making it easier to visualize.

7. Place print in dark box and place UV light over the hole in the box.
8. Allow the print to dry.
9. Label the print and describe what you saw under the UV light.
10. Identify and mark at least 5 different ridge characteristics on the print.

Part 2: Silver Nitrate

Purpose: The purpose of this lab is to use a chemical technique to develop fingerprints.

Materials: 4'x 4" slips of paper
Tweezers
Tray with silver nitrate solution
Paper towels
UV light source
UV goggles
Chemical goggles
Tray with fixer solution
Popsicle sticks

Precautions: When working with UV light, UV goggles must be worn. Chemicals used in this lab are very caustic to the skin. Use gloves, goggles and aprons during this lab.

Procedure:

1. Place fingerprints on paper.
2. Using tweezers, immerse print in $AgNO_3$ for 5-10 minutes.
3. Remove paper with tweezers and drain excess liquid. YOU MUST WEAR GLOVES DURING THIS LAB!
4. Place the paper between 2 paper towels and dry it. Once dry, expose the fingerprint to bright sunlight or longwave UV light.
5. To develop the print, immerse the print in fixer solution for 15-20 min.
6. Using tweezers, remove the print from the fixer solution and blot dry.
7. Affix print to an index card.
8. Identify 5 ridge characteristics on the print.

Part 3: Fluorescent Fingerprint Powder

Purpose: To use the fluorescent properties of a fingerprint powder to visualize and enhance a latent fingerprint.

Materials: Fluorescent fingerprint powder
Fingerprint brush
Black paper
Tape
UV flashlight
UV goggles
Gel pen

Precautions: Use VERY LITTLE fingerprint powder. Lightly dip the brush in just what is on the lid of the jar. That will be more than enough powder.

Procedure:

1. Wipe down an area of your table so that there are no stray fingerprints in the area.
2. Place fingerprints on the clean black table top.
3. Using the fluorescent powder, gently brush the area until the fingerprints become visible.
4. Place a strip of tape over the fingerprints. Gently press the tape into the print.
5. Smoothly remove the tape and place it on a black piece of paper.
6. In a darkened area, examine your fingerprint with a UV flashlight. NOTE: YOU MUST WEAR ORANGE SAFETY GOGGLES WHILE USING THE UV LIGHT!
7. Using a gel pen, note at least 10 points of minutia on your fingerprint.

Appendix 6. Microscope Lab

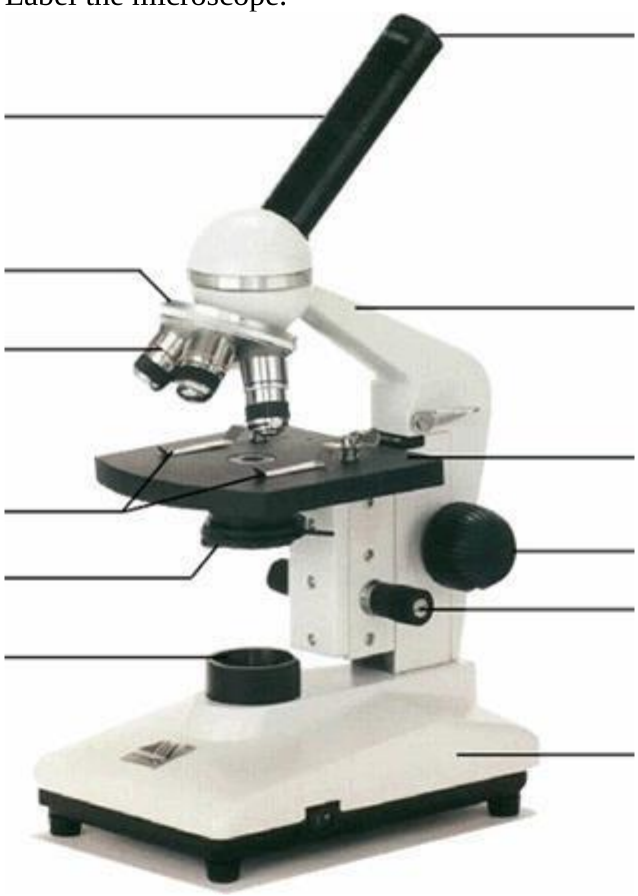
Adapted from Texas CTE Resources: Lesson Plan – Forensic Use of Light

Basic Use of a Microscope

Note: Always use the lowest objective first. Use the coarse adjustment knob to focus as well as you can first, then use the fin adjustment knob to fine-tune the focus. Once you are focused on the lowest power, you can use the next highest objective. Never use the coarse adjustment knob on any objective other than the lowest. You might crush the slide and you will see nothing.

Materials:	compound microscope	variety of prepared slides
	dropper bottle of water	newspaper
	microscope slides	cover slips
	scissors	tweezers

1. Label the microscope.



2. How do you calculate the power of magnification?

3. Calculate the powers of magnification for each objective lens:

Band Color	Objective Power	Eyepiece Lens Power	Power of Magnification

4. What happens to the view of an image as you increase the power of magnification?

5. Make a wet mount slide of the letter “e” cut from the newpaper.
    a. Place the letter “e” right side up on a clean slide.
    b. Place 1-3 drops of water on the “e”. Do not use more water than that.
    c. Place the edge of the cover slip on one side of the “e” in the water.
    d. Carefully drop the cover slide onto the “e”.

6. Look at the slide under the lowest power. What is unusual about the image?

7. Draw what you see at three different magnifications. Label each drawing.

Magnification Levels:

Low Power: ______X Medium Power: _______ X High Power: ______X

Appendix 7. Flame Test Demonstration

Name: ___Teacher Version_______________________________ Date: _________ Block: _______

Flame Test Lab

Purpose: The purpose of this lab is to understand how different metal and metalloid ions can be identified by determining the color of the flame produced when they are burned.

Materials:

Water-soaked popsicle sticks Obtain enough popsicle sticks for each lab group to have at least five sticks. Soak them overnight in a container of distilled water. Do not touch the sticks with your bare hands after this point as the salts on your fingers can interfere with the test. On the day of the lab, wearing gloves, empty the container and rinse the sticks with fresh distilled water.

Bunsen Burners

Lighters

Beakers with water (for putting out the sticks) Put out five beakers with water at the front of the room and label them "Unknown #1" through "Unknown #5" for students to place their used sticks in.

Unknown powders #1 - #5 This part will depend on the inventory in your chemistry department. Some of more commonly available materials are lithium, calcium, copper, sodium, barium, and potassium. Try to get elements or compounds that will give students five different colors. If you have two materials that each give off a blue-green flame, they will have no way to distinguish the materials in this lab. Use the following table to help select your materials. NOTE: Some of the materials in this list are very toxic (e.g. Arsenic). If you are unsure about the toxicity or safe handling of any of the substances you choose to use, please discuss safe handling and disposal procedures with a knowledgeable person in your chemistry department or consult the MSDS sheets for those materials.

Gloves

Goggles

Color Group	**Color**	**Material**
Reds	Magenta	Lithium compounds
	Scarlet or crimson	Strontium compounds
	Red	Rubidium
	Orange-Red	Calcium compounds
Yellows	Gold	Iron
	Intense yellow	Sodium compounds
Greens	Emerald	Copper (II) non-halide
	Bright green	Boron
	Faint green	Antimony and NH_4 compounds
	Yellow-green	Barium, manganese (II)

Blues	Azure	Lead, selenium, bismuth, cesium, copper (I), indium, $CuCl_2$
	Light blue	Arsenic
	Greenish-blue	$CuBr_2$, antimony
Purples	Violet	Potassium compounds (not borates, phosphates or silicates)
	Lilac to red-purple	Potassium, rubidium

Procedure:

1. Google and watch "Flame Test 07" on You Tube.
2. Put on your gloves and goggles.
3. Obtain five water-soaked popsicle sticks from the front table and place them on a clean, dry paper towel.
4. Obtain a container of one of the unknown powders from the front table.
5. Carefully open the container and dip the end of one stick into the powder. Do not dip it in more than 1 cm deep.
6. Close the container.
7. Light your Bunsen burner.
8. Slowly wave the unknown powder on the stick through the flame and observe all changes to the flame. Record your observations.
9. Place your used stick in the appropriate beaker on the front table and return the unknown powder container to the front table.
10. Repeat steps 6 through 11 for the remaining four unknowns.
11. Clean up your work area. You MUST keep your goggles on as long as anyone's Bunsen burner is on.

Analysis

1. How can the differences in flame color be used in forensics? Describe a scenario when this test could be useful to a case.
   Unknown substances found at a crime scene could be burned to check for flame color. Elements and compounds emitting certain colors can be identified in this manner. For example, a table at a crime scene contains small piles of a gray powder, along with scales, glassine envelopes, copper wire and containers of nails. Suspecting a possible bomb-making operation, you flame test the gray powder at the scene. The flame turns a faint green in the presence of the powder. You conclude that the powder could be antimony (a component of gunpowder) or an ammonium compound (used in explosives). You immediately confirm you are dealing with a bomb-making situation.
2. What causes the flames to be different colors? Hint: You may need to do some outside research to fully answer this question.
   The heat of the flame causes the electrons in the substance to become excited and jump to a higher energy level. When those electrons fall back to their original energy levels, they emit a photon, which is a packet of light energy. Each element has its own unique energy levels when excited and therefore emit a signature spectrum from which they can be identified.
3. Based on your observations and the information in the Flame Color Chart below, what are the identities of the five unknown powders? Justify your answers.

See data table. Results will depend on what substances you used for your unknowns.

Data Table Flame Test.

Unknown #	Initial Observations	Flame Observations	Identity of Unknown
1			
2			
3			
4			
5			

Flame Test Colors

Symbol	Element	Color
As	Arsenic	Blue
B	Boron	Bright green
Ba	Barium	Pale/Yellowish Green
Ca	Calcium	Orange to red
Cs	Cesium	Blue
Cu(I	Copper(I)	Blue
Cu(II)	Copper(II) non-halide	Green
Cu(II)	Copper(II) halide	Blue-green
Fe	Iron	Gold
In	Indium	Blue
K	Potassium	Lilac to red
Li	Lithium	Magenta to carmine
Mg	Magnesium	Bright white
Mn(II)	Manganese(II)	Yellowish green
Mo	Molybdenum	Yellowish green
Na	Sodium	Intense yellow
P	Phosphorus	Pale bluish green
Pb	Lead	Blue
Rb	Rubidium	Red to purple-red
Sb	Antimony	Pale green
Se	Selenium	Azure blue
Sr	Strontium	Crimson
Te	Tellurium	Pale green
Tl	Thallium	Pure green
Zn	Zinc	Bluish green to whitish green

Name: __(Student Version)____________________________ Date: _________ Block: _______

Flame Test Lab

Purpose: The purpose of this lab is to understand how different metal and metalloid ions can be identified by determining the color of the flame produced when they are burned.

Materials:

Water-soaked popsicle sticks
Bunsen Burners
Lighters
Beakers with water (for putting out the sticks)
Unknown powders #1 - #5
Gloves
Goggles

Procedure:

1. Google and watch "Flame Test 07" on You Tube.
2. Put on your gloves and goggles.
3. Obtain five water-soaked popsicle sticks from the front table and place them on a clean, dry paper towel.
4. Obtain a container of one of the unknown powders from the front table.
5. Carefully open the container and dip the end of one stick into the powder. Do not dip it in more than 1 cm deep.
6. Close the container.
7. Light your Bunsen burner.
8. Slowly wave the unknown powder on the stick through the flame and observe all changes to the flame. Record your observations.
9. Place your used stick in the appropriate beaker on the front table and return the unknown powder container to the front table.
10. Repeat steps 6 through 11 for the remaining four unknowns.
11. Clean up your work area. You MUST keep your goggles on as long as anyone's Bunsen burner is on.

Analysis

1. How can the differences in flame color be used in forensics? Describe a scenario when this test could be useful to a case.
2. What causes the flames to be different colors? Hint: You may need to do some outside research to fully answer this question.
3. Based on your observations and the information in the Flame Color Chart below, what are the identities of the five unknown powders? Justify your answers.

Data Table Flame Test.

Unknown #	**Initial Observations**	**Flame Observations**	**Identity of Unknown**
1			
2			
3			
4			
5			

Flame Test Colors

Symbol	Element	Color
As	Arsenic	Blue
B	Boron	Bright green
Ba	Barium	Pale/Yellowish Green
Ca	Calcium	Orange to red
Cs	Cesium	Blue
Cu(I	Copper(I)	Blue
Cu(II)	Copper(II) non-halide	Green
Cu(II)	Copper(II) halide	Blue-green
Fe	Iron	Gold
In	Indium	Blue
K	Potassium	Lilac to red
Li	Lithium	Magenta to carmine
Mg	Magnesium	Bright white
Mn(II)	Manganese(II)	Yellowish green
Mo	Molybdenum	Yellowish green
Na	Sodium	Intense yellow
P	Phosphorus	Pale bluish green
Pb	Lead	Blue
Rb	Rubidium	Red to purple-red
Sb	Antimony	Pale green
Se	Selenium	Azure blue
Sr	Strontium	Crimson
Te	Tellurium	Pale green
Tl	Thallium	Pure green
Zn	Zinc	Bluish green to whitish green

Appendix 8. Color Lab

The Color Lab allows students to experiment with how different substances and objects will appear under different wavelengths of light with different color filters. Once students have a good understanding of how different wavelengths of light will interact with various items, they will study various substances such as blood, urine, saliva, and gasoline with the lights and filters. Finally, they will be given one or more "crime scenes" to examine with the light sources for latent evidence.

This lab uses UV flashlights as well as the two most common types of visible light used by crime scene investigators – white light and blue light. Regular flashlights can be used for the white light, the more powerful the better. Evident sells a blue light kit with an orange filter for $179.00. (https://www.shopevident.com/category/forensic-light-sources/orion-lite-deluxe-455nm-blue-light-kit) There are many others on the market as well. Amazon has a set of five 9-LED UV flashlights for $12.00.[29] Different colored gels from your theater department make excellent filters for the students to work with.

To set up this lab, I gathered sets of objects in as wide a range of colors as I could find. For example, I found red, pink, orange, yellow, green and blue paper clips, the same colors of string, and paper squares colored with a range of magic marker colors. You can use anything that comes in a range of colors. I glued these objects to a poster board ("Color Board") to minimize them disappearing during lab. I used a board with a dark blue background, but any color will work. Just have your students explain what, if any, effect the background color has on what they see!

Using swatches of white fabric, I then collected samples of animal blood (from the butcher), saliva, urine (placing cloth on used cat litter works for this), sweat, grease and gasoline. A few drops of each liquid is all you need. I also included a few liquids I would not expect to see fluoresce such as vegetable oil, red wine and barbeque sauce. For health reasons, I encased all biological samples in sealed Ziploc bags and attached the bags to the poster board ("Knowns Board") so the students never touch them. On three separate small boards, I attached three different samples of some these substances and marked them "Crime Scene #1" through "Crime Scene #3."

For the first board, students use the different lights and filters as shown in the data table below to examine the different colored objects and record their findings. You can duplicate this table as many times as necessary for the number of items you have for them to examine. Students should stop after completing the first board and draw some conclusions about what they have observed. How do the different colors (wavelengths) of light interact with differently colored objects? What light/goggle combinations are the best for observing each color?

The Knowns Board should be examined next. Students should record their observations as before for each of the known substances. The more detailed their observations, the more accurate they will be when identifying the unknowns. Once they have examined all of the knowns, depending on time and class size, you can have them work to identify substance(s) at one or more "Crime Scenes." You can make each crime scene so it only has one unknown substance for students to identify or you can use multiple substances at each scene. Students should be assessed on the thoroughness of their observations, the accuracy of their identification of the unknown(s) and their justifications for their choices.

Goggles with UV protection are a must during this lab. AmazonBasics Antiscratch Safety Glasses[30] are one possibility. The Data Table below is sufficient to record observations for three items. Copy the Data Table as many times as is necessary to record the data for all of the items you have for your students.

Data Table 1.

Item:			**Item:**			**Item:**		
λ (nm)	**Filter**	**Observations**	**λ (nm)**	**Filter**	**Observations**	**λ (nm)**	**Filter**	**Observations**
White	Red		**White**	Red		**White**	Red	
	Orange			Orange			Orange	
	Yellow			Yellow			Yellow	
455	Red		**455**	Red		**455**	Red	
	Orange			Orange			Orange	
	Yellow			Yellow			Yellow	
UV	Red		**UV**	Red		**UV**	Red	
	Orange			Orange			Orange	
	Yellow			Yellow			Yellow	

Analysis

Identify each of the unknowns on your crime scene board. Use your collected data to justify your conclusions.

Student Resources

"Forensic Light Source Applications: Wavelengths and Uses." HORIBA. Accessed September 8, 2020. https://www.horiba.com/fileadmin/uploads/Scientific/Documents/Forensics/fls.pdf

Easy to read and understand pamphlet that introduces the student to Alternative Light Sources and the different wavelengths of light used in forensics.

Teacher Resources

Marin, Norman, and Jeffrey Buszka. *Alternate Light Source Imaging: Forensic Photography Techniques*. London: Routledge, 2016.

Excellent resource for the basics about light as a wave and a particle, particularly Chapter One. The rest of the book focuses on forensic photography and is rather technical and only applies if you have the proper cameras and lenses.

"TX CTE Resource Center." Lesson Plan: Forensic Use of Light | TX CTE Resource Center. Accessed September 20, 2020. https://www.txcte.org/resource/lesson-plan-forensic-use-light.

Terrific outline of the use of light in various areas of forensic science. There are many activities and assessments that can be easily adapted to use in the classroom.

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