Illuminating Mysteries: Energy and Spectroscopy in Forensic Science

by Jackie Smith, 2014 CTI Fellow
William Amos Hough High School

This curriculum unit is recommended for:
Honors Forensic Science, Physical Science
Or as extension material in Honors Chemistry
11th and 12th Grades

Keywords: forensic science, spectroscopy, chromatography, toxicology

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

Synopsis: This unit looks at the nature of light and its use in spectroscopy in forensic science to identify unknown substances. Light is studied from the development of the theory of the dual nature of light to the properties of light that allow it to be used in spectroscopy. The use of spectroscopy as a tool in the identification of unknowns (drugs, inks, paint, etc…) is explored. The unit offers several activities involving first chromatography and then spectrometry to allow students to gain a deeper understanding of these concepts and to see how science can help solve crimes.

I plan to teach this unit during the coming year to 240 students in Honors Forensic Science.

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Jackie Smith

Rationale

This curriculum unit focuses on the branch of forensic science which analyzes drugs, toxins and poisons known as toxicology. Students will learn about various legal and illegal drugs and their effects on the human body. They will study the past when arsenic was known as "inheritance powder." They will look at toxins and their use in espionage in the recent past. Bioterrorism will be addressed with cases such as the anthrax mailings and the Tokyo subway attacks. Cases of celebrity overdoses will bring home the dangers of mixing drugs in the body. While the case studies capture student interest, focus will move to the techniques used to identify and quantify drugs and poisons. Various forms of chromatography and spectroscopy will be studied. Chromatography is a technique used to separate mixtures into their component parts. Spectroscopy is then used to identify the components and determine the quantities present. When dealing with drugs, the amount involved is the basis for criminal sentencing so students will learn how important precision and accuracy are in the toxicology lab.

By the end of this unit, I want students to know how to recognize whether drugs may be present at a crime scene. They will know how to recognize and collect evidence of drugs, toxins and poisons at crime scenes. Students will know not just how to analyze the substances that might be found, but will understand how and why those analytical techniques work. Students will be able to compare and contrast thin layer, liquid and gas chromatography as well as ultraviolet-visible, infrared and mass spectrometry. They will be able to apply these techniques in the appropriate circumstances. Students will conclude the unit with preparation for a mock trial where they will integrate their knowledge of the science of toxicology with the practicalities of the criminal justice system.

William Amos Hough High School is a large suburban high school of almost 2500 students located in the small town of Cornelius, North Carolina. We opened our doors in 2010 to serve the northern part of the Charlotte-Mecklenburg School District. Ninety-five percent of our graduates go on to either two- or four-year colleges. Twenty-nine percent of our students are minorities. We offer a comprehensive college preparatory program in the arts and sciences. Classes are taught at the Standard and Honors levels and we offer 22 Advanced Placement courses in conjunction with the College Board. Our science program requires one earth science (Earth and Environmental Science or AP Environmental Science), Biology, and one physical science (chemistry, physics or physical science). Biology, chemistry and physics are also offered at the AP level.

Students are required to take either a fourth year science or social studies course. We are offering Honor Forensic Science for the first time this year to meet that requirement. With the overwhelming popularity of television shows such as the CSI franchise, NCIS, Forensic Files and others, we believe this course will grab students' interest while teaching them valuable lab skills and critical thinking.

Charlotte-Mecklenburg Schools has established a set of Essential Standards for the course. Student learning objectives are defined and various resources are suggested. A company called Crosscutting Concepts, Inc. produces a series of kits which offer a hands-on laboratory experience for most of the units in the course based on a continuing storyline called "The Mystery of Lyle and Louise." Each kit is designed for 30 students and our school district purchases one set of kits for each high school that offers Honors Forensic Science. With some supplementation and a lot of creativity, we are able to offer realistic forensic lab experiences to approximately 240 students this year. Laboratory exercises are supplemented with case studies, readings, current events, guest speakers, student-designed projects and a summative Mock Trial to offer a well-rounded introduction to science in criminal investigations.

Background

The word "forensics" comes from the Latin "forensis" meaning forum.[1] The Roman forum was a place for Senators and citizens alike to air their grievances and settle disputes. Forensic Science is the evolution of the forum to mean the application of science to the law.[2] The role of science as applies to the law is to evaluate physical evidence to such a degree as to provide a measure of reliability that the evidence actually says what it purports to say.

There are many fields of forensic science encompassing the study of all types of evidence, from blood and other bodily fluids to handwriting to explosives. Evidence can be divided into two broad categories: biological and physical.[3] Biological evidence includes anything that comes from a thing, living or deceased, human, animal or botanical. Examples of biological evidence include plant parts, fibers from plants, blood, saliva and semen. Physical evidence is everything else that did not come from life. For example, tire marks, gunshot residue, drugs and blood spatter patterns are all physical evidence.

In court, forensic scientists need to be able to identify items of evidence recovered in the course of an investigation. The goal is to be able to identify each piece of evidence so specifically that it can be linked to a single person. Evidence that can point to a specific person is called individual evidence. A DNA profile is specific to an individual. A fingerprint is unique to a single person. Most evidence, however, does not point to a single suspect, but rather indicates a group of people from which the perpetrator will come. This evidence, called class evidence, encompasses things like hair color, bullet types, clothing fibers and anything else that is not unique but could have come from a class of people.

Every type of forensic evidence has various techniques which are particularly effective in its identification. There is a group of techniques used to visualize physical and biological evidence. Spraying Luminol or Blue Star reagents at the scene of the crime to detect the presence of blood is one example of an identification technique. The detection of blood at a crime scene involves a simple chemical reaction between any blood present at the scene and the illuminating agent such as Luminol or Blue Star. Cyanoacrylate (Super Glue) fuming for latent fingerprints is another example of a technique used to visualize evidence otherwise not visible to the naked eye.

Sometimes the evidence may be visible but its identity may not be apparent. For example, in a hit-and-run, one car hits another car, or even a person, and then leaves the scene of the crime. Often when this happens, some trace evidence – a bit of paint or a piece of broken glass – is left behind. The goal of law enforcement is to find the hit-and-run driver and bring him to justice. In order to find the offender, it is essential to gather as much information as possible from that bit of paint or broken glass. Using a technique called spectroscopy, forensic scientists are frequently able to identify the make, model, year and color of the vehicle involved in the crash, thereby significantly narrowing the pool of suspects.

Spectroscopy at its simplest is shining a beam of light through a sample and observing what comes out the other side or it is measuring the characteristics of the light that the sample emits after it interacts with the exciting beam. It is the interaction of energy (a beam of light) with a sample to perform an analysis.[4] In order to understand how spectroscopy works, a look at light itself is the first step.

Development of Spectroscopy

History of the Study of Light

The study of light dates from ancient Greece. In 300 B.C., Euclid studied the properties of light. In his work *Optica*, he proposed that light traveled only in straight lines.[5] This was the earliest wave theory. In the 1660's the work of Pierre Gassendi was published in which he discussed the theory that light is made up of particles.[6] Issac Newton built on Gassendi's work and in 1675 published *Hypothesis of Light* in which he suggested that light is made up of "corpuscles" which were emitted in all directions from a source.[7] Newton did not subscribe to the wave theory because he knew the waves bend around objects and light does not.

Around the same time, Robert Hooke, was working on his pulse theory to explain colors and compared the spreading of light to that of waves on water.[8] A few years later, Christian Huygen worked out a mathematical theory of light that stated that light is emitted in all directions as a series of waves which travel through a hypothetical substance called "luminiferous ether."[9] The wave theory of light allowed that waves could interfere with each other and in 1800 Thomas Young conducted a diffraction experiment that showed light behaving as waves.[10] Young also postulated that different colors are the result of different wavelengths of light. By the mid 1800's, the particle theory of light had temporarily disappeared.

In 1900, Max Planck suggested that while light is a wave, light waves could only gain or lose energy in discreet amounts related to their frequency.[11] He called these discreet amounts "quanta" which later came to be called photons. In 1905, Albert Einstein explained the photoelectric effect by saying that electrons were absorbing energy in chunks (quanta) all at once.[12] If light were a wave, the energy should be absorbed at a slow and continuous rate.

The wave model of light explained most of the observed behaviors of light, but not all. The remaining behaviors could only be explained if light energy was in bundles called quanta. Therefore light had both wave and particle characteristics. This duality of the nature of light became the basis for the branch of science called quantum mechanics.[13]

Electromagnetic Spectrum

Radiation is the energy emitted from one body, transmitted through a medium or space and absorbed by another body.[14] Electromagnetic waves are produced by a vibrating electric charge so they have electric and magnetic components. Electromagnetic radiation is energy emitted as electromagnetic waves, such as radio, x-ray, infrared and visible light waves. The continuous range of electromagnetic frequencies is called the electromagnetic spectrum. This spectrum is broken down into regions based on how electromagnetic waves interact with matter. Figure 1 shows the electromagnetic spectrum.

Electromagnetic radiation, EMR, is defined by several characteristics including its wavelength and frequency. The wavelength is the distance from the same point on one wave to the next and the frequency is how many waves pass a given point in a set amount of time. The higher the frequency, the shorter the wavelength; the lower the frequency, the longer the wavelength. When EMR interacts with single atoms and molecules, its behavior depends on the amount of energy per quantum it carries.[15] The amount of energy it carries is directly related to its frequency.

Different wavelengths of visible light have different frequencies associated with them. The wavelength of visible light ranges from 400 to 700 nanometers (10^{-7} meters). Most of the time, the light will have a combination of photons with a mix of different colors. The example of selecting the colors to see them all is when white light is shown through a prism or off of a CD and we see the rainbow of color produced. This color mix is called a spectrum. This is how we describe colors. When light has the following wavelengths described in Table 1, we see the associated colors.

Figure 1. The Electromagnetic Spectrum

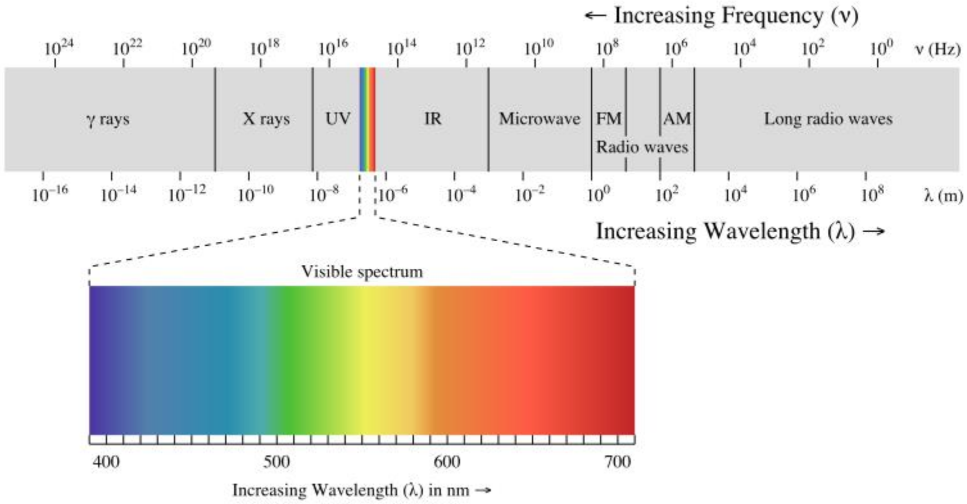

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Table 1. Wavelengths and Colors

780-620 nm	620-597 nm	597-577 nm	577-492 nm	492-455 nm	455-390 nm
Red	Orange	Yellow	Green	Blue	Violet

Long wavelengths — Short wavelengths
Low frequencies — High frequencies

All objects are made of atoms and molecules which contain electrons that vibrate at specific frequencies, called their natural frequencies, as well as a variety of natural vibrations among the atoms of the molecule. When the frequency of the light wave that interacts with the sample does not match the natural frequency of the electrons or vibrational modes of the atoms within the material, the light will pass through the object which is called transmission. If the object is opaque like a mirror, the light will be reflected. Again, in reflection and transmission, the light does not have any noticeable change in properties (wavelength and frequency) or change in its mix of colors (spectrum).

When a wavelength of light hits an object tuned to the same natural frequency as the electrons or the vibrational modes, the object absorbs the energy from the light wave and excites. Because different molecules have different natural frequencies, they will absorb light at different frequencies and the characteristics of the excited molecule can then serve as a unique "fingerprint" of the molecule to identify it.

We can observe the change in any of three ways. One way is to pass the light through the sample and look at the change in the spectrum of the light at the other end. This is called *absorption*. An example of this would be to pass white light through a red dye solution. The observer on the other end will then see the light that is now red in color because the dye absorbed the blues and yellows of the light. A second method is called *emission*. The newly excited molecule will eventually try to find ways to get rid of the excess energy. Sometimes this results in the sample itself emitting a characteristic spectrum of light. Glow-in-the-dark toys are examples of this type of property; the toy is exposed to a lamp to excite it and then it will glow. The last method involves exposing a sample to light which then scatters it like a reflection except it has subtly stolen a quanta or packet of energy from the light that corresponds to the energy of some of the natural frequencies within the molecule. This effect is a kind of absorption process called *Raman*.

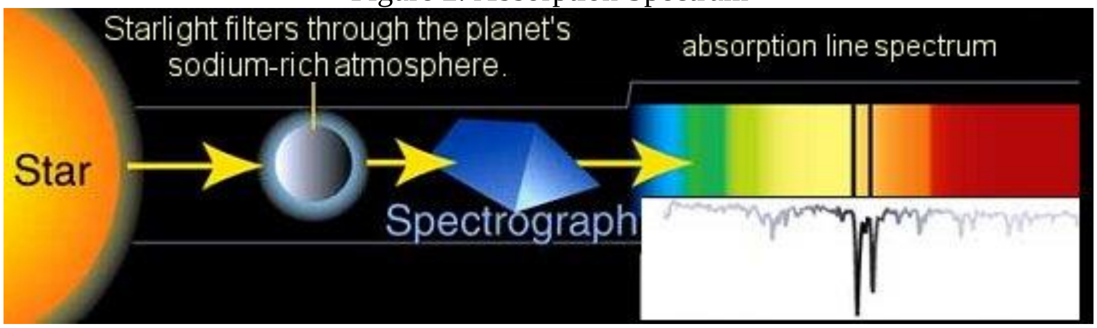
Spectroscopy

Spectroscopy is the measure of the spectrum of light energy after its interaction with a material. Every kind of atom and molecule interacts with light in a unique way. The goal of spectroscopy is to look closely at this spectrum which ultimately identifies the amounts and components of substances so precisely that the sample source is now uniquely identified. By observing and measuring the results of the light's interaction with a material, the unique "fingerprint" of that material can be determined.

There are many forms of spectroscopy. Some such as Gamma Ray Spectroscopy, X-Ray Spectroscopy and Infrared (IR) Spectroscopy use EMR at different points on the electromagnetic spectrum. Astronomical Spectroscopy studies energy from celestial sources to determine the chemical composition of stars while Electron Spectroscopy measures the changes in energy levels of electrons in an atom. The forms most relevant to forensic science are UV/Vis Spectroscopy (an absorption spectroscopy), IR Spectroscopy (an absorption spectroscopy), Raman Spectroscopy (previously described) and Gas Chromatography/Mass Spectrometry (GS/MS).

Ultraviolet/Visible Light (UV/Vis) spectroscopy uses light from the visible and ultraviolet ranges of the EMR spectrum to determine the absorption spectra of materials. The energy of the electrons at the natural frequency of the material is absorbed and the remaining wavelengths of light are reflected. The absorption spectrum is determined by the atomic and molecular composition of the material. In Figure 2, the dark lines on the spectrum represent energy that is absorbed and those energies correspond to specific atoms and molecules which make up the star emitting the light.

Figure 2. Absorption Spectrum



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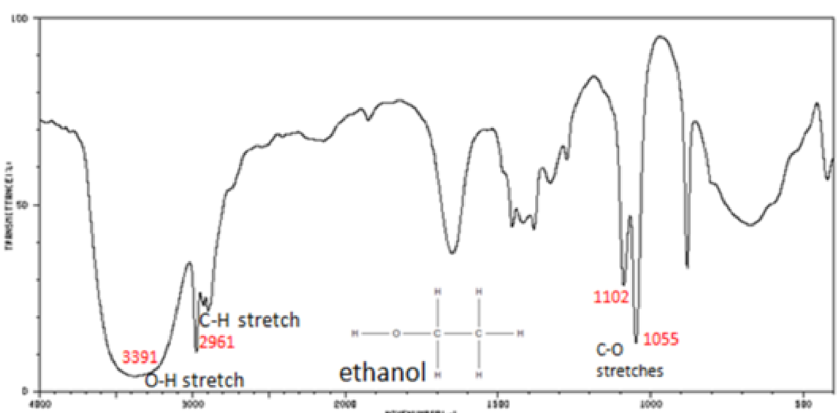
IR spectroscopy works by passing a beam of light from the IR range of the EMR spectrum through a sample to be identified and then studying the resulting absorption spectrum.[16] These spectra are unique to each of the vibrations between the atoms of the molecule. Because each compound has different combinations of atoms, it follows that they will also have different vibrations. IR spectroscopy requires a sample of the material to be studied to be prepared for use in such a way as to destroy a small amount of the evidence. This is a liability when the purpose of identifying the evidence is to use it against a defendant in court. Below in Figure 3 is an IR spectrum showing the various elements and functional groups found in a sample of ethanol.

Figure 3. IR Spectrum of Ethanol



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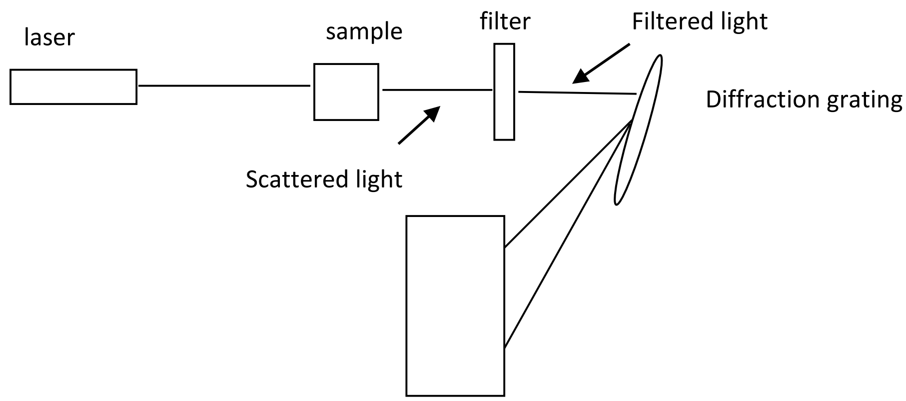
The Raman Effect was first observed in 1923 and since the 1990’s its use in forensic science has taken off. Raman spectroscopy involves shooting the sample with a certain wavelength, λ, of light, using a laser, and then collecting the wavelengths, λ', that bounce off the sample. It is the difference between the ingoing wavelength and the outgoing wavelength that is called the Raman Shift. This shift is again like IR due to the vibrations of the atoms within the molecule that are unique to each molecule and produces a fingerprint of the substance being studied. Raman spectroscopy has several major benefits. It requires very little, if any, sample preparation. It is also non-destructive which means the entire sample is still available to be tested again, by the same or other means, by the defendant in court, making its admissibility into evidence much more likely. Below, Figure 4, is a diagram of the Raman process showing the initial scattering of light and then the collection and identification of the scattered light.

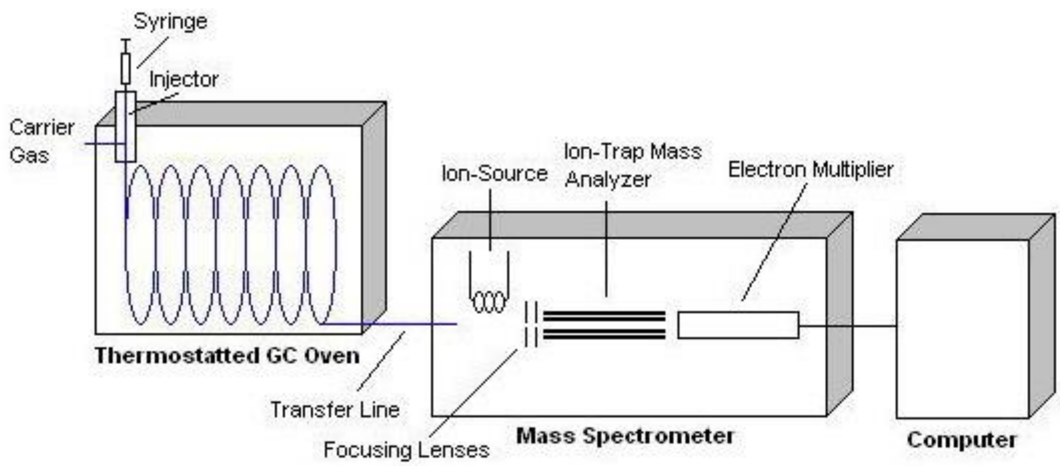
Figure 4. Simplified Diagram of Raman Spectroscopy



Hand-held Raman spectrometers are being developed, due to advances in miniaturization that are faster, more rugged and less expensive than traditional designs. These hand-held devices include on-board spectral libraries for reference. These models can be taken out into the field for on-scene investigations substantially improving turnaround times.[17]

GS/MS is a two-part process which separates mixtures into their component parts and then identifies and quantifies the parts. A sample of the unknown material enters the gas chromatograph through an injection port where it is mixed with an inert gas (frequently helium) which will carry it through the instrument. At this point, the sample is instantly heated to 300°C which vaporizes the sample. It then passes through a specially treated column inside an oven which heats the sample further and separates the components based on their volatility or ability to vaporize. The matter then passes to the mass spectrometer where it is first bombarded with an ionization source. The material is stripped of electrons forming positive ions, or cations. The cations are passed through a magnetic field which separates them by mass. The smaller ions move at faster speeds and the heavier ions move more slowly. The separated ions reach a detector which counts how many of each sized ion is present in the sample. This information is fed to a computer which plots the abundance of ions versus their mass, producing a graph that is called a mass spectrum. This mass spectrum shows what compounds are in the sample and in what quantities.[18] This information is unique to each material and acts as a "fingerprint" of the sample. Below is a simple diagram of the process in a gas chromatograph/mass spectrometer.

Figure 5. Workings of GC/MS



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Applications of Spectroscopy to Forensic Science

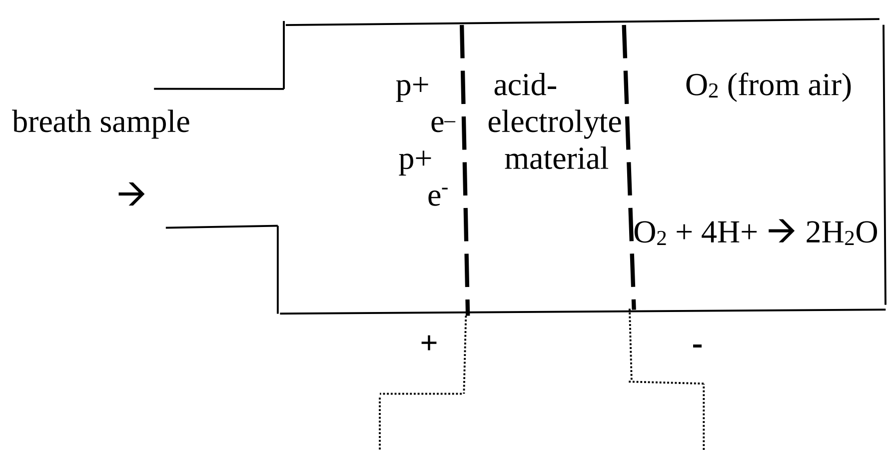
Spectroscopy has many applications in forensic science. Some of the most common are in toxicology, questioned document analysis, fiber analysis and the analysis of paint and glass chips. Forensic Toxicology is the study of drugs and poisons in the context of legal proceedings including "their chemical composition, preparations and identification. It includes knowledge about the absorption, distribution and elimination characteristics of such substances in the body."[19] There are chemical analyses of over 9,500 different inks in the International Ink Library,[20] a database going back to the 1920's, and questioned document examiners need to be able to identify the source of the ink on documents to lead to the uncovering of the writers of ransom notes, threat letters and fake wills as well as perpetrators of white collar crimes. GC/MS is the most common type of spectroscopy used for these purposes.

UV/Vis spectroscopy is used in forensic labs to analyze the dyes and pigments in individual textile fibers, microscopic paint ships and the color of glass fragments.[21] IR spectroscopy has been used to measure breath alcohol content, to analyze drug, fiber and paint samples and to visualize wounds such as bruises and bite marks on tissue. It has been used to detect blood and explosives.[22] Strides are being made in using spectroscopy to determine post-mortem interval (PMI) or time since death. Scientists, realizing that at death bones start to lose water and proteins in the bones begin to decompose, studied pig bones over a three month period. They used a form of near-IR spectroscopy and found a correlation between the spectra and the age of the bones since death. They developed a mathematical model to determine PMI which hopefully will serve as a basis for developing such a model for human bones.

Another daily use of spectrometry in forensic science is the use of the Intoxilyzer 5000. Police officers spend a good deal of effort trying to get drunk drivers off the road. When they first stop a suspected drunk driver, they perform a variety of field sobriety tests (FSTs). These include the Walk-and Turn test (a test measuring a person's balance, coordination and ability to follow directions), the Horizontal Gaze Nystagmus test (a test checking the amount of involuntary eye movement said to be correlated with one's state of intoxication) and other simple coordination and memory tests. Officers need reasonable suspicion to believe that the suspect is impaired by alcohol or some other impairing substance. The results of the FSTs can be a strong indication of that. The other test routinely performed is the administration of the Alcasensor (or similar brand product).

The alcasensor detects the chemical reaction of alcohol in the breath in a fuel cell. The fuel cell has two platinum electrodes with a porous acid-electrolyte material in between. When the suspect blows into the machine, air from the suspect's lungs passes the first side of the fuel cell. The platinum there oxidizes any alcohol in the air to produce acetic acid, protons (H^+) and electrons. The electrons flow through a wire from the platinum electrode. The wire is connected to an electric current meter and the second platinum electrode. Protons move through the fuel cell and combine with oxygen and electrons on the other side to form water. The more platinum that is oxidized, the higher the electric current will be. An attached microprocessor measures the current and calculates the blood alcohol content.[23] Below is a diagram of a simple alcasensor machine.

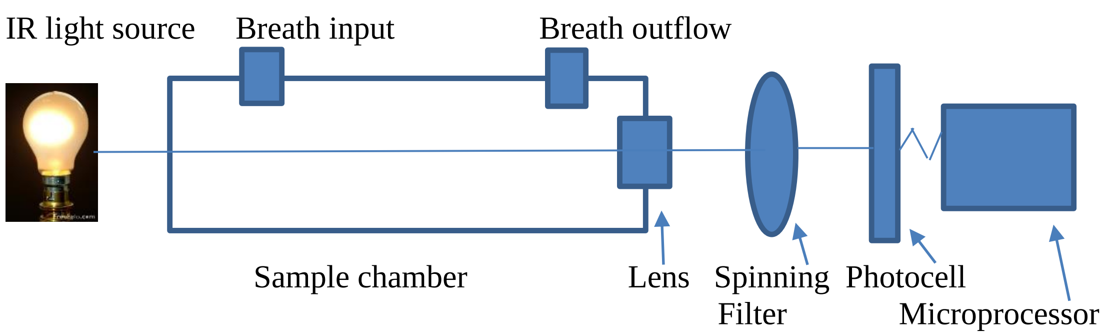
Figure 6. Diagram of the Working of an Alcasensor



While the alcasensor is a valuable device for use in the field, its results are not always accurate. In fact, the alcasensor reading is not admissible as evidence in court. An officer can only testify as to whether the result gave him probable cause to believe that the suspect was impaired. A much more accurate and reliable test is necessary to use as evidence in a court of law.

That reliable evidence comes in the form of the Intoxilyzer 5000, a device that detects alcohol by the use of infrared spectroscopy. This is the machine used at the police station when a suspect is arrested. The reading on this machine is considered evidence of impairment and is potentially admissible in court. The basic premise of the Intoxilyzer is that all molecules interact differently with IR light. All molecules are constantly vibrating. These vibrations change in the presence of IR light. The changes include bending and stretching of various bonds inside the molecule. Each type of bond absorbs IR light at different wavelengths. If you know how different bonds change in the presence of IR light, you can determine what substance is present and in what quantity. The Intoxilyzer looks at the various bonds in ethanol (C-C, C-H, C-O, O-H) and measures their absorption. The absorbed wavelengths of IR light identify the molecule as ethanol; the amount of absorption describes how much ethanol is present in the sample. Below, Figure 7, is a diagram of an Intoxilyzer machine.

Figure 7. Intoxilyzer Machine



The lamp puts out IR light at multiple wavelengths. This beam passes through the sample chamber and is focused by the lens onto the spinning filter wheel. The filter wheel contains filters for the specific wavelengths of the bonds in ethanol. The light that passes through at each wavelength is detected by the photocell and converted to an electrical impulse. This impulse is sent to the microprocessor which calculates the blood alcohol content.[24]

Learning Objectives

Charlotte Mecklenburg School standards for high school Honors Forensic Science focus on the techniques of UV-Vis spectroscopy, thin layer chromatography, IR spectroscopy and Gas Chromatography/Mass Spectroscopy. The activities in this unit focus on using these techniques in the area of toxicology.

Students will understand that there are destructive and non-destructive methods to evaluate unknown samples of evidence and the advantages and disadvantages of each. Students will develop an understanding of chromatography as a means of separating mixtures into their component parts so that those parts may then be identified. They will study different types of chromatography including liquid, thin layer and gas chromatography. Students will learn that the primary method of identification of unknown samples of evidence is spectroscopy. They will understand the concept of spectroscopy as the interaction of light energy with a sample for the purpose of identifying the sample as precisely as possible. UV-Vis and IR spectroscopy are absorbance techniques that produce spectra unique to each substance. Students will gain an understanding of absorption and transmittance as they relate to absorbance spectra. They will also study and interpret the spectra produced by a mass spectrometer and how that technique differs from UV-Vis and IR.

Teaching Strategies

Forensic Science lends itself well to many different types of teaching activities. Currently in my classroom I have a crime scene set up which students have been working with since the first day of school. Our victim, Vicki, lies on the floor behind crime scene tape, dried blood on her head where she apparently hit it on a marble obelisk She has two small bullet holes in the back of her shirt. There is dried blood spray on the wall over her body. Two shell casings, a button (not from her clothing), and some hairs and fibers litter the scene. A metal lamp with fingerprints on it is turned over on the floor next to her. We have worked the crime scene learning how to secure and sketch a crime scene and then how to identify, collect and label evidence.

Lecture

Brief lectures will be used to introduce main concepts to students. Lectures will be accompanied by PowerPoint presentations that include interactive warm ups and brief spot assessments of student understanding.

Case Studies

There are numerous example of deaths related to drug overdoses and poisonings. Students will explore the cases of spies, celebrities and terrorists. Names students might recognize include Michael Jackson, Whitney Houston, Phillip Seymour Hoffman, Kurt Cobain, Heath Ledger, Anna Nichole Smith, Marilyn Monroe and many more. Russian Spy Alexander Litvinenko was killed with polonium-210, a radioactive isotope. Everything from arsenic to anthrax has been used to bring about the deaths of people from political dissidents to unwanted spouses. Students will study and report on toxicological cases to determine fact patterns, methodologies and motives.

Labs

Two main labs will anchor this unit. The first is a liquid chromatography/spectroscopy lab. Students will use a liquid chromatography apparatus to separate different flavors of Kool-Aid into their components. After separating the colors, students will use a UV-Vis spectrometer to analyze the absorbance of the components and graph their results, creating a spectrum for their Kool-Aid.

We will use the lab kit from "The Mystery of Lyle and Louise" furnished by the school district which pertains to toxicology. It is called Prescription for Crime and focuses on drug detection and analysis. Students are given a scenario in which two suspects in the murder of Louise Mondelo and another person are caught with 13 grams of an unknown white powder which is suspected to be illicit drugs. The students will conduct color tests to determine what drug(s) might be present. Then they will qualitatively analyze the mass spectra of several major illicit drugs and compare them against the unknown sample to identify the illegal substance involved. They will conclude with a quantitative analysis of the mass spectra of the correct drug to determine how much of the drug was present and how to charge the defendants.

Other Activities

I will bring in a law enforcement officer who can discuss and demonstrate the use of the Breathalyzer in the search for impaired drivers. Students will have an opportunity to experiment with the device and explore questions about its use in criminal court.

Our end of year activity is a Mock Trial bringing together all of the skills and knowledge students have acquired during the course. Students will prepare the roles of prosecutors, defense attorneys and expert witnesses for each of the main areas of forensic science we have studied. They will put on evidence from each of the units in this class (i.e. Blood spatter patterns, fingerprints, shoe prints, etc…). Students will brainstorm the facts necessary to present the toxicology evidence within the North Carolina Rules of Evidence and begin to lay out their testimony in this area.

Lessons

Essential vocabulary for this unit includes the following terms: chromatography, gas chromatography, liquid chromatography, thin layer chromatography, electromagnetic spectrum, infrared, visible, ultraviolet, wavelength, frequency, absorption, transmission, emission, spectrum, screening test, confirmatory test, spectrophotometry, spectroscopy, mass spectroscopy, color test, LD-50, metabolite, drug, poison, toxin, qualitative analysis and quantitative analysis

Day 1

Students will begin with a brief formative assessment via the interactive Google application Pear Deck. This allows me to analyze the results in real time and adjust my lesson accordingly. They will then watch a short video on the history of the development of toxicology at http://ed.ted.com. Students will then break into three groups and have 10 minutes, with the use of their personal technology devices, to develop a definition of drug, poison and toxin for the class. Students will present their work. They will then read two articles: "Investigating Death from Inhalant Abuse" by Daniel Morgan and "When Good Science Goes Bad" by Tim Graham. In small groups, students will discuss the articles and develop informational posters about the articles. They should include information about the differences in collecting evidence in drug versus poison cases. Students will present their posters to the class and finish up with a brief reflection on what they learned that day and what they still have questions about.

Day 2

Students will begin with a warm up which presents several scenarios in which drugs, including alcohol, toxins or poisons are suspected in deaths. Students will be asked to identify the evidence and indicators leading to those suspicions. Students will then receive background notes on the types of chromatography used in forensic science and the situations in which each would be the most beneficial. Students will then conduct a liquid chromatography lab in which they use chromatography columns to separate the different flavors of Kool-Aid into their component colors and compare their results. They will view a brief video from You Tube about the procedures they will follow such as "Kool-Aid Chromatography" (https://www.youtube.com/watch?v=Q6pGleEzIGk). The components will be saved for the next day. Students will then be presented with background information on spectroscopy. This will include the nature of light and the ways in which light interacts with a sample to identify that sample. The basic workings of a UV-Vis spectrometer will be covered. Our school has a basic Fisher Scientific Spectrometer we will use. Students will conclude with a reflection on the way chromatography works to separate mixtures. Any notes not reached in class will be assigned for homework.

Day 3

Students will begin by diagramming the workings of a UV-Vis spectrometer. They will then take their samples from the day before and learn how to use a UV-Vis spectrometer to determine absorption at different light frequencies. Students will plot their data, creating a unique spectrum for Kool-Aid. While student are taking turns working with the spectrometer, they will be completing an interactive activity at www.rice.edu/forensics called CSI Experience. They will work on Case 4 – Toxicology. The interactive introduces students to the various pieces of equipment in a toxicology lab and how to collect evidence in an arson investigation to look for the possible use of accelerants. Students will conclude with an analysis of their spectroscopic findings.

Day 4

Students will begin by taking notes on the science of toxicology. They will then conduct Lab 1 from the Lyle and Louise kit Prescription for Crime which involves color testing various substances to determine what the evidence found in the suspects' vehicle might contain. They will begin Part 2a of the lab which is an analysis of GC/MS data on various illicit drugs with the aim of determining what their unknown sample contains. Students will receive the study guide for this unit. They will also choose their case studies from a list of cases to be covered and begin their research at home.

Day 5

Students will begin by summarizing their findings during their qualitative analysis in lab yesterday. They will then begin Part 2b of the lab which is a quantitative analysis of their unknown sample. When they are done, students will summarize their results, answer a series of post-lab questions and decide what the defendants should be charged with in criminal court. Students will then have class time to complete their case study research and develop their presentations. They will complete their presentations for homework.

Day 6

Students will begin by reading an article on the Breathalyzer which is used by law enforcement to evaluate drivers for alcohol impairment and writing down questions they have about the device and its use in law enforcement. We will have a guest speaker from our local police department who will demonstrate the device and talk about impaired driving. Students will have an opportunity to ask questions and test the device themselves. Students will be asked to apply their knowledge of light absorption to determine how the Breathalyzer can estimate a person's blood alcohol level. They will learn that the results of a Breathalyzer are not admissible in court but can contribute to probable cause to arrest a suspect, whose blood alcohol level must them be confirmed in another manner such as a blood test. Afterwards, students will begin their case study presentations.

Day 7

Class will begin with a brief question and answer period. Students will then take the unit test which will consist of short response questions based on scenarios and data provided.

After the test, students will finish presenting their case studies. Once the tests are graded, they will be returned to the students for them to evaluate their mastery of the unit objectives. An instrument designed for that purpose will be provided.

Summary

It is my hope that this unit will introduce students to the field of toxicology in a fun and engaging manner. I want them to walk away with a deeper understanding of what drugs, toxins and poison are, the roles they have played in history, the ways in which they can be detected and how that information is used in a criminal context.

Notes

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[2] http://thelawdictionary.org/forensic-evidence/. October 15, 2014.
[3] http://www.nfstc.org/pdi/Subject01/pdi_s01_m01_01.htm. October 15, 2014.
[4] http://www.Chemistry.about.com/od/analyticalchemistry/a/spectroscopy.htm. September 19, 2014.
[5] http://deskarati.com/2011/02/04/euclids-optics/. October 16, 2014.
[6] http://plato.stanford.edu/entries/gassendi/#10. September 19, 2014.
[7] http://www.thestargarden.co.uk/NewtonAndLight.html. September 19, 2014.
[8] http://www.newtonproject.sussex.ac.uk/view/texts/normalized/NATP00005. September 26, 2014.
[9] http://enlightenyourmind.net/History/huygens.html. September 26, 2014.
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[21] http://en.wikipedia.org/wiki/Ultraviolet%E2%80%93visible_spectroscopy. October 24, 2014.
[22] Marshall, Laura S., Applications: Spectroscopy in Forensics http://www.photonics.com/Article.aspx?AID=36234. September 23, 2014.
[23] "How Breathalyzers Work" by Craig Freudenrich ,Ph.D. www.electronics.howstuffworks.com/gadgets/automotive/breathalyzer2.htm. November 8, 2014.
[24] *Ibid.*

Reading List for Students

Forensic Toxicology by Ian Murnughan, Exploring Forensics
http://www.exploreforensics.co.uk/forensic-toxicology.html
This is a brief article the current applications of toxicology and procedures for collecting samples.

The Big Book of Celebrity Autopsies, *Ed.* Kevin Viani, Skyhouse Publishing 2013.
This is a collection of copies of actual autopsy reports from various entertainers, political figures and notorious criminals which makes for interesting reading and a good resource for student projects.

Materials for Classroom Use

"Investigating Death from Inhalant Abuse," Daniel Morgan
http://www.evidencemagazine.com/index.php?option=com_content&task=view&id=1080&Itemid=49

"When Good Science Goes Bad," Tim Graham
www.chemistry.org/education/chemmatters.html
These articles outline a drug overdose case and a poisoning case and highlight the differences in collecting evidence in each type of case.

http://ed.ted.com/lessons/early-forensics-and-crime-solving-chemists-deborah-blum
This is a brief, entertaining look at the development of toxicology from the early 20th century.

"The Mystery of Lyle and Louise" Prescription for Crime lab kit

This kit is available through www.crosscuttingconcepts.com or through scientific catalogues. It allows student to work with real gas chromatography and mass spectroscopy data.

The CSI Experience www.rice.edu/forensics Case 4 - Toxicology
This interactive resource familiarizes students with the various equipment in the toxicology lab and how to collect evidence for use in the lab.

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Appendix 1

Charlotte Mecklenburg Schools Essential Standards for Honors Forensic Science Toxicology

- HS-FS-T-1a Students will understand that drugs, toxins and poisons may not be apparent at a crime scene and will learn the types of indicators present.
- HS-FS-T-2a Students will be able to describe the difference between drugs, toxins and poisons.
- HS-FS-T-2b Students will be able to describe and perform the proper steps of collection and preservation of drug evidence in the field.

Students will learn to differentiate between drugs, poisons and toxins and learn how to recognize and collect evidence of them at crime scenes.

- HS-FS-T-3a Students will understand the process of isolating and identifying drugs, toxins and poisons in human tissue.
- HS-FS-T-3b Students will understand and appreciate the difficulties in isolating drugs, toxins and poisons in human tissue.

Students will learn how tissue samples are collected and what types of tests are available in the toxicology lab to identify them.

- HS-FS-T-3c Students will be able to compare and contrast chromatography, UV/VIS/IR spectrophotometry and mass spectrophotometry.

Students will learn about and perform different types of chromatography to separate mixtures. Students will learn about the properties of light and how it is used in spectrometers to identify and quantify drug and poison samples. Students will work with a UV-Vis spectrometer and with mass spectrometer data.