Infrared Spectroscopy in Forensic Paint Chip Analysis

Katie Cofrin
Grade level: 6th-8th grade
Chemistry-Spectroscopy
Time estimate: 1 day/50 minutes

OVERVIEW

The concept of spectroscopy will be revisited. Infrared spectroscopy (IR) will be introduced as an analytical technique in chemistry. Students will be “investigating” a hit-and-run crime by analyzing paint chip sample data. Forensic chemistry focus will give the lesson a CSI approach.

PURPOSE

This lesson is important because it uses problem solving, critical thinking, and a fun approach to spectroscopy in chemistry. Students will qualitatively and quantitatively analyze actual paint chip spectra from an IR database and use those observations to determine which suspect they think committed the crime.

OBJECTIVES & STANDARDS MET

Objective: Students will be able to use critical thinking and spectroscopy analysis to determine which suspect they think committed a fictitious crime. Students will gain an understanding of the technique of spectroscopy and its importance in everyday chemistry.

Standards 1.1, 1.2, 1.3, 1.5b, 2.5, 2.6, 2.7, 2.8, 2.10

BACKGROUND INFORMATION & REFERENCES

Students must have a clear understanding of energy and the electromagnetic spectrum. Knowledge in chemical bonds and molecular structures is very helpful.

2. SBDS (spectra database)
3. www.google.com (paint chip pictures)
5. Orgchem.colorado.edu/hndbksupport/irtutor/IRtheory.pdf (IR theory)

VOCABULARY, MATERIALS, PREPARATION, SAFETY

Vocabulary: Forensic, infrared, spectroscopy, molecular vibrations, spectra/um, energy, absorption, organic molecule, pigment

Supplementary documents [enclosure]

No safety concerns.
Infrared Spectroscopy in Forensic Paint Chip Analysis

Katie Cofrin
Grade level: 6th-8th grade
Chemistry-Spectroscopy
Time estimate: 1 day/50 minutes

METHOD: 5 E’S MODEL

Describe the step-by-step procedures for each E of the 5 E’s model:
[Engage] Show clip (see #6 in background information section) of actual investigator discussing importance of paint chip analysis in forensics. Discuss “crime scene” and students role in the investigation (see student worksheet).

[Explore] Allow students to use their own critical thinking to determine which facts are important in the crime given an information section on worksheet.

[Explain] Introduce IR spectroscopy and how it assists in forensics: IR is a method that utilizes energy absorption to create curves or plots in an IR spectrum. Resident will discuss how the radiation energy that is absorbed by organic molecules is converted to molecular vibration. This can only happen though, if the radiant energy matches the energy of a specific molecular vibration. The vibrations produce the peaks or curves found in an IR spectrum.

[Elaborate] Show IR spectra of paint pigment samples and have students narrow in on a suspect (3 suspects given).

[Evaluate] Quiz/test will contain a spectra question. Students will be given a spectrum specific to a certain color and will be asked to match it to database spectra to determine which color their sample is.

EXTENSIONS & CONNECTIONS

Possible extensions include discussion of other evidence that IR may be used for, alternative spectroscopy techniques that can be applied to biological evidence and other forensic samples. Visiting a lab or showing a spectroscopy instrument would also be very useful as a visual aid.

HANDOUTS & PRESENTATIONS

Attached.
In a residential neighborhood at approximately 1:30 pm, the owner of a green suburban reported being the victim of a hit-and-run. The suspect fled in a vehicle of unknown make and model.

A local back surveillance video caught black and white film of 3 different vehicles that were in the area at that time.

Your job is to narrow down the list to one suspect that you think committed the crime, based on IR paint chip analysis data and other relevant information.

**SUSPECT #1**
- No criminal record
- Owns a blue pickup truck
- Was on lunch break at the time of the incident

**SUSPECT #2**
- Previous minor traffic violations
- Owns a green compact car
- Was driving home from work at the time of the incident

**SUSPECT #3**
- Has a suspended license
- Owns a red truck
- Was borrowing his wife’s truck at the time of the incident

A foreign blue paint chip from the victim’s suburban was taken, along with a small chip from each of the suspected vehicles. After analyzing IR data, you will need to decide who you believe was the perpetrator.
QUESTIONS

1. By looking at the suspect information, suggest a reason for each of the suspects to leave the scene of the crime.

2. Can you eliminate any suspects right away? Explain.

3. Use the data sheet to determine which of the paint chips matches the one found on the victim’s vehicle.

4. Name one thing you learned about Infrared Spectroscopy.
Sample #1: Analysis of paint chip from victim’s vehicle.

Compare the sample above obtained from the victim’s vehicle to the three samples from the suspect vehicles. Can you determine which suspect’s vehicle matches the IR analysis from the victim’s vehicle? Explain below which suspect you believe committed the hit and run and support your claim with evidence.
Forensic Science

Paint Chip Analysis by Infrared Spectroscopy
Paint Chip Analysis

- How does a paint chip help in CSI?
## Car Paint Database

**Code:**

**Wild Card:**

**Manufacturer:**

**Year:**

**Paint Line:**

**Gloss:**

**Enter Colour Name:** BLUE

**Colour Name:** ALL

**Model:** ALL

**Application:** ALL

**Colour Class:** BLUE

**Colour Type:** ALL

---

<table>
<thead>
<tr>
<th>Paint Line</th>
<th>Colour</th>
<th>Year</th>
<th>Type</th>
</tr>
</thead>
<tbody>
<tr>
<td>BAYERISCHE MOTOREN WERKE</td>
<td>BLAU</td>
<td>1978-1990</td>
<td></td>
</tr>
<tr>
<td>BAYERISCHE MOTOREN WERKE</td>
<td>BLAU</td>
<td>1979-1990</td>
<td>97/98</td>
</tr>
<tr>
<td>BAYERISCHE MOTOREN WERKE</td>
<td>BLAU</td>
<td>1980-1980</td>
<td>91/92</td>
</tr>
<tr>
<td>BAYERISCHE MOTOREN WERKE</td>
<td>GENDARMERIE BLAU</td>
<td>1977-1999</td>
<td></td>
</tr>
<tr>
<td>BOMBARDIER</td>
<td>BLUE</td>
<td>9126A</td>
<td>CMU9126A</td>
</tr>
<tr>
<td>BOMBARDIER</td>
<td>BLUE</td>
<td>J809</td>
<td></td>
</tr>
</tbody>
</table>

---

**Options**

**Variant**

**Color Tool**

**MPV**
Typical Car Paint Layers

- Clear Coat
- Colour Coat
- Base Coat
- Metal/Plastic Bodywork
Multi-Layer Paint Chip
Infrared Analysis (IR)

The Electromagnetic Spectrum

Penetrates Earth Atmosphere?

<table>
<thead>
<tr>
<th></th>
<th>Y</th>
<th>N</th>
<th>Y</th>
<th>N</th>
</tr>
</thead>
<tbody>
<tr>
<td>Radio</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Microwave</td>
<td>10^{-2}</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Infrared</td>
<td>10^{-5}</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Visible</td>
<td>.5 x 10^{-6}</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Ultraviolet</td>
<td>10^{-8}</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>X-ray</td>
<td>10^{-10}</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Gamma Ray</td>
<td>10^{-12}</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Wavelength (meters)

About the size of...

Buildings
Humans
Honey Bee
Pinpoint
Protozoans
Molecules
Atoms
Atomic Nuclei

Frequency (Hz)

10^4  10^8  10^{12}  10^{15}  10^{16}  10^{18}  10^{20}

Temperature of bodies emitting the wavelength (K)

1 K  100 K  10,000 K  10 Million K
IR works by exposing organic molecules to IR radiation.

- When the radiant energy matches the energy of a specific molecular vibration, absorption occurs.
- This energy is absorbed and converted into energy of molecular vibration.
Molecular Vibrations

- Each bond in the molecule will vibrate and have a special absorbance
- Example: water
Paint Chip Sample

- Paint chips have organic molecules in them that respond to IR radiation.
Paint Pigment Molecules

- Green
- Blue
# Neighborhood Search

Craig Tennenhouse  
Grade 8  
Time length: One 50 min class period

## OVERVIEW

This lesson introduces students to concepts and applications related to Euler circuits in graphs. They will examine graphs in the form of small neighborhood street maps, make conjectures regarding necessary and sufficient conditions for a graph to be Eulerian, and apply those conjectures to a larger graph.

## PURPOSE

This lesson engages students in mathematics related to the resident's research area. It also demonstrates how applications can arise from theoretical mathematics.

## OBJECTIVES & STANDARDS MET

**Objective:** Students will practice making conjectures and working on mathematics in small groups, developing more of an understanding of the work of a mathematician. Students will also learn a necessary and sufficient condition for a graph to be Eulerian, and apply it to a real-world model.

**Standards:**  
1: Students develop number sense and use numbers and number relationships in problem solving situations and communicating the reasoning used in solving these problems.  
2: Analyze and extend patterns to create general rules and visual representations when investigating problems as well as apply to real-world situations.

## BACKGROUND INFORMATION & REFERENCES

**Background:** Students will have seen simple graphs (vertices and edges). They will also have developed their own conjectures about graph theoretic properties and worked in small groups to verify those conjectures, but this is not necessary for the lesson to be implemented.

**References:** No references, but this lesson is in conjunction with Resident Scientist’s lesson of police forensics.

## VOCABULARY, MATERIALS, PREPARATION, SAFETY

**Vocabulary:** Graph, Eulerian, Circuit  
**Materials:** Overhead display, multiple copies of 3 maps: small eulerian, small non-eulerian, large  
**Preparation:** Students will be divided into pairs and given one of the two small maps (see handouts #1 & #2). Slides with both maps 1 (eulerian_map.gif) & 2 (noneulerian_map.gif) should be prepared ahead of time. The same should be prepared for the larger map (big_map.pdf).  
**Safety:** No safety concerns.
### METHOD: 5 E’S MODEL

Describe the step-by-step procedures for each E of the 5 E’s model:

**Engage:** Some students (about half) will have recently finished a spectroscopy lesson with the Resident Scientist within the context of a hit and run crime scene. Our students will be informed of the science lesson (if they are in a different science class) or reminded of it. During the course of the science lesson students will have determined the responsible party. The Resident Mathematician will then explain that the suspect is in one of two neighborhoods and it's their job to assure efficiency of the police department by determining whether or not the neighborhoods can be searched under the restriction that every street be traced, the searcher return to the police station, and no street is retraced.

**Explore:** Photocopies of two neighborhoods (one Eulerian and the other not; see handouts #1 & #2) will be passed out to student working in pairs. They will try to find an appropriate path in their given map, (though this is only possible for half of the students).

**Explain:** From those who found a path, a volunteer will present it on the smartboard. Those who didn't will be asked to make a conjecture about why such a path cannot be found. Students will be led as necessary to arrive at the conclusion that only those maps that contain only street corners with even valences will be Eulerian. An Eulerian circuit will finally be defined as a path on a graph both beginning and ending at the same vertex and which includes every edge exactly once.

**Elaborate:** A much larger Eulerian map (big_map.pdf) will be presented at the smartboard and students will work on their own to determine whether or not an Euler circuit is present. Since finding such a circuit will be very difficult on this map due to its size, a discussion of non-constructive proof of existence will commence; students will be asked how to determine whether or not an Eulerian circuit exists, and how one could verify their answer. The resident will remind students that the job of the “police consultant” on this case is just to determine existence and not necessarily a solution, which will lead to an opportunity for the resident to explain non-constructive proofs.

**Evaluate:** Within one or two weeks of the lesson implementation, students will be given a short quiz wherein they will be asked to draw figures that (a) can be drawn without picking up their pencil or retracing while returning to the starting point, (b) can be drawn without picking up their pencil and not returning to the starting point, and (c) can not be drawn in either way, with explanations of their answer. This will serve to determine both whether or not the students recall their conjecture and their ability to extend this conjecture to other problems with graph theoretic models.

### ADAPTATIONS OR DIFFERENTIATED LEARNING

Advanced class (Algebra): We will discuss graph theory in the context of modeling a neighborhood. Less advanced classes will receive more assistance in developing a conjecture.

### EXTENSIONS & CONNECTIONS

A discussion of other applications of such a problem will be a part of the lesson. Examples: might include communications, street sweeping, and UPS delivery drivers.

### PEER REVIEW COMMENTS

Resident worked with lead teacher and resident scientist.
[How does this lesson integrate your research into the classroom?]
This lesson focuses on graph theory, my particular area of research. It also re-introduces the idea of mathematical conjecture and proving non-existence.

[How could the lesson be improved?]
I would like to have used a map of the school but there were not enough intersections to make it an interesting part of the exercise.
Lead Teacher- Possibly using a map of Englewood, where students recognize the streets and have more buy in. However, adding the Simpson theme to the maps we used gave a lot of buy in to the students.

[What worked well?]
I think most students were engaged. They work well in small peer groups, and a number of students really rose to the challenge of a difficult problem.
Lead Teacher- I think Craig did an excellent job of allowing students to explore the various maps to come up with their conjecture.

[What did you learn?]
Giving students time to develop their own conjecture, with a small amount of leading if necessary, really seems to resonate more than a simple explanation of a topic.
Lead Teacher- I agree because the kids came up with their conjecture on their own, they really seemed to better explain why it works.

[How does this impact your future profession?]
The above insight should be helpful in teaching upper division students in higher math classes.
Lead Teacher- Seeing the power of allowing the students time to really explore to discover rules and how they truly can explain why they work makes me realize the importance of this time.

[Further thoughts...]
I just really enjoyed the lesson, and I think a number of students did as well. I think it was good to revisit the idea of conjecture since they had forgotten the definition from the previous lesson (Bagels and Planarity). It was also a good impetus to discuss the life of a graduate student.

In addition, after implementing the assessment, it is clear that a better assessment tool could have been constructed. The students seemed to have a lot of trouble extending the street map model to the diagram tracing model in the short period of time allocated for the quiz. After discussions between the lead teacher and resident we believe that recording the quiz in terms of the street map model (e.g. “Construct a street map with the following properties...”) would have elicited much more useful information about the students' learning. This is supported by a short second assessment in which a small sample of students from various sections were given the maps used in the lesson and asked to either complete an Euler circuit or explain why one does is not present. Every student tasked demonstrated an excellent understanding of the class-developed conjecture and how it was to be implemented. However, we also feel that a single extension question (like one of those given in the original assessment) is appropriate.

STUDENT WORK EXAMPLES (COMPLETED AFTER LESSON IS IMPLEMENTED)
The student work was simply tracing and erasing around the passed out maps. They weren't retained since there is no way to differentiate a successful attempt from an unsuccessful one.

HANDOUTS & PRESENTATIONS