

Who murdered Sir Ernest?

Solve the mystery with spectral fingerprints

Introduce your students to acoustic and optical spectra with a hands-on murder mystery.

By Ernst Hollweck and Johannes Almer

This collection of forensic activities highlights the power of spectral analysis and the links between acoustic and optical spectra. In the first activity, students use sound to solve a murder mystery, analysing acoustic spectral 'fingerprints' to identify the murderer from his wine glass. The second activity requires the student detectives to investigate optical spectra by carrying out flame tests of single metal ions and

compounds. In the third activity, students vary the voltage applied to light-emitting diodes (LEDs) to understand the link between photons and spectral colours. Finally, all three activities are brought together in a poster session.

The activities are suited for students aged 14–16 and use readily available laboratory or domestic materials. The three activities plus the poster session require no more than three hours.



Image courtesy of Nicola Graf

Image courtesy of Nicola Graf / Johannes Almer and Ernst Hollweck



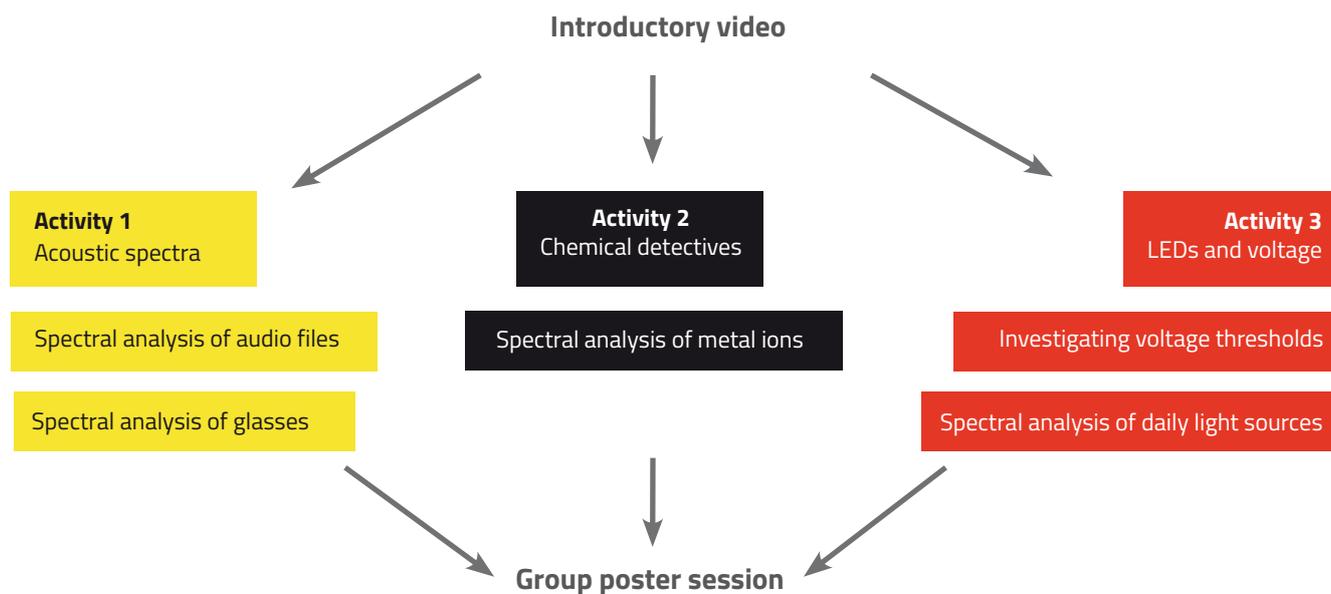


Figure 1: The interdisciplinary activities start with a video before groups of students work on three interrelated topics. The lessons conclude with poster presentations

Activity 1: Acoustic spectra

At a grand ball last night, the host, Sir Ernest, was murdered. Now it's up to your students to find the murderer, using acoustic spectral fingerprints.

The search for the murderer starts with a video^{w1} (figure 2). Sir Ernest greets his first guest – “Nice to see you, Mr Darcy” – and they clink wine glasses.

The scene is repeated for another two guests, Mr Bennet and Mr Bingley, each of whom is associated with the sound of a specific glass. When making the video, rather than clinking each guest's glass with Sir Ernest's, we actually struck them gently with a hammer. This produced an identifiable sound for each glass, uncomplicated by the sound from Sir Ernest's glass.

Next comes the murder scene, during which Sir Ernest talks to one of the three guests without mentioning his name. The two men clink glasses once again, before the murderer pulls out a knife and kills Sir Ernest. This time, the recorded sound really does come from both the murderer's wine glass and Sir Ernest's. Now the young detectives can begin solving the mystery. The three activities (a, b and c) in this section can be assigned to different groups of students according to their abilities. At the end of the lesson, each group should present their results to the class as a poster.



- ✓ Chemistry
- ✓ Physics
- ✓ Acoustics
- ✓ Criminology
- ✓ Spectroscopy
- ✓ Quantum mechanics
- ✓ Ages 14–19

Experimental activities can offer students the opportunity to feel like real scientists and can make science more appealing. In the three interdisciplinary activities outlined in this article, students use concepts from both chemistry and physics to solve a murder case.

Before starting the activities, students could think about the different tests used in criminology and the disciplines on which they are based. All the materials required for the experiments are readily available and the instructions are easy to follow. The activities provide options for students of different abilities and can be performed in small groups. Students can share their conclusions and learn how to work co-operatively.

The text could be used as a starting point for discussing the importance of science and interdisciplinary collaboration to find solutions for everyday problems.

Mireia Güell Serra, Spain



Figure 2: Scenes from the introductory video, showing Sir Ernest greeting a guest (top), and the murder (bottom)

a) Matching acoustic spectra

In this part of the activity, the students use audio software to analyse the characteristic sound of each guest's glass and identify the murderer by comparing the resulting acoustic spectra. They will need about 45 minutes.

Materials

- Computer with Audacity or other audio software^{w1}
- Audio files from the murder scene^{w2}

Procedure

Ask your students to:

1. Use the audio software to analyse the four audio files (Mr Darcy's glass, Mr Bingley's glass, Mr Bennet's glass, and the murder scene). For each file, they should produce an acoustic spectrum: a plot of frequency (in hertz) against relative loudness as perceived by the human ear (in A-weighted decibels, or dB(A)). Using the acoustic spectra, they should identify the single spectrum of the murderer within the spectrum of the murder scene.

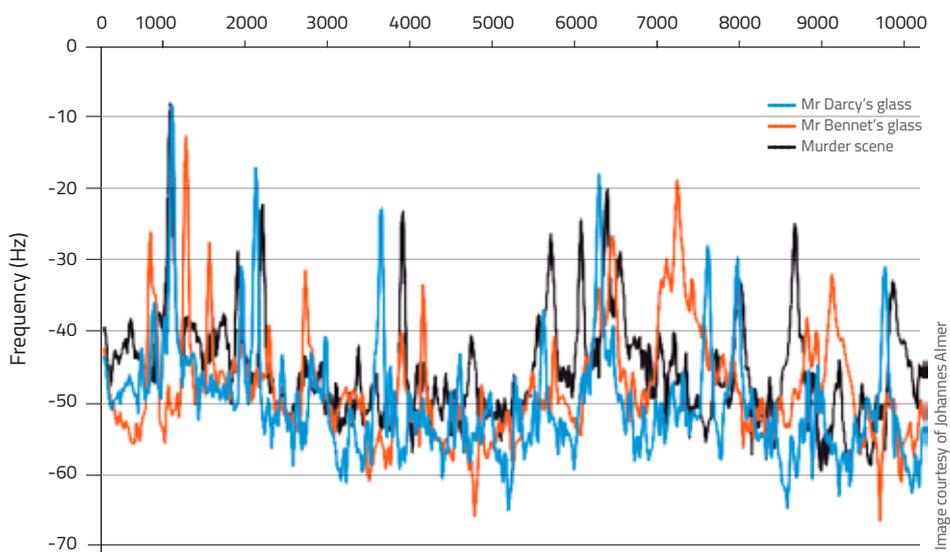


Figure 3: Frequency analysis reveals the innocent guests: the spectra for Mr Darcy and Mr Bennet's glasses do not match the spectrum from the murder scene.

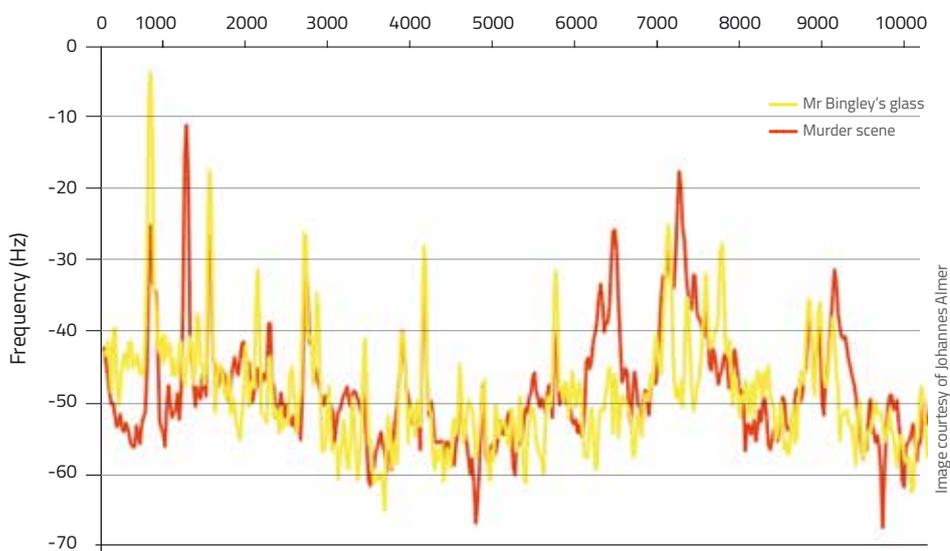


Figure 4: Frequency analysis reveals that Mr Bingley is the murderer.

2. Compare these spectra (figures 3 and 4) to determine the murderer: the spectrum of the murderer's glass resembles the spectrum from the murder scene.

Further instructions on how to use Audacity can be downloaded from the *Science in School* website^{w2}.

b) Smartphone spectra

Using smartphones, the students analyse the characteristic pitches of different glasses. The activity takes about 30 minutes.

Materials

- A selection of assorted glasses (e.g. wine, champagne, water)
- Hammer (or other object to strike the glasses)
- Smartphone with a frequency analysis app^{w3}
- Paper and pencil

Procedure

Ask your students to:

1. Strike each glass gently with the hammer. Use the smartphone app to record the acoustic spectrum of each glass.
2. For each glass, record the frequency of the most noticeable peaks in a table.
3. Using paper and pencil, sketch the spectrum (frequency against amplitude) for each glass, using the values recorded in your tables.

Alternatively, your students could analyse the audio recordings from the murder video and sketch the spectra.

c) Playing with pitch

In the last part of this activity, the students use smartphones to investigate the effect that the fullness of a glass has on its pitch when struck with a hammer. They will need about 30 minutes.

Materials

- At least five identical wine glasses
- Hammer (or other object to strike the glasses)
- Smartphone with a tuner app^{w4}
- Water
- Measuring cylinder (or other means of measuring the volume of water)

Procedure

Ask your students to:

1. Pour a different volume of water into each glass, noting the amount in each glass.
2. Strike each glass gently with the hammer. Use the smartphone app to record the frequency of the resulting pitch.
3. Display the results graphically, for example as a histogram (figure 5).

Activity 2: Chemical detectives

Not only has Mr Bingley been accused of murder, but now the food hygiene at his home, Netherfield Hall, has been called into question!

After dinner, a guest called Mr Wickham sprinkles the remains of the chicken on

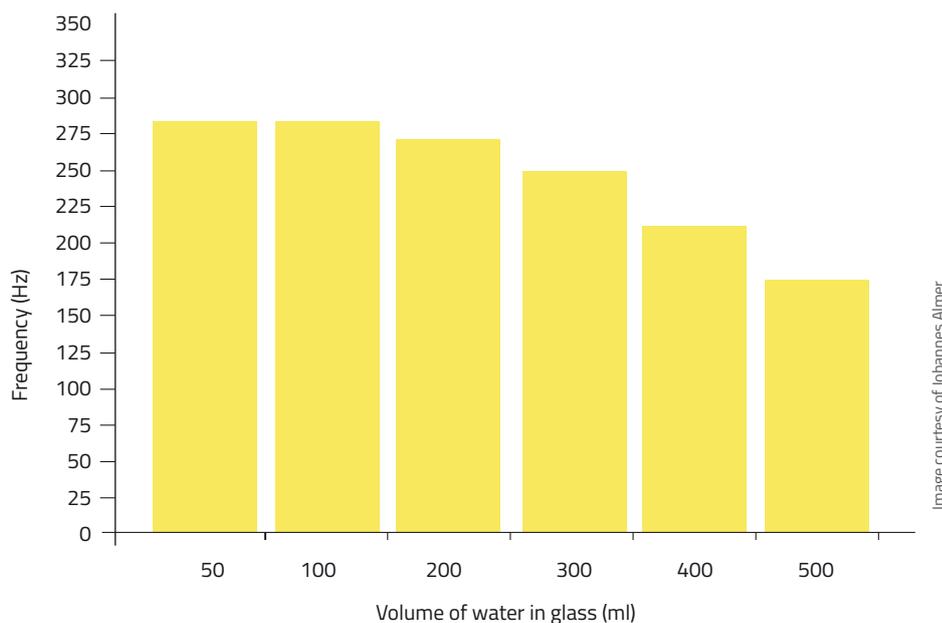


Figure 5: Example histogram showing that the pitch of the glass decreases with increasing volume of water

his plate with lithium chloride (LiCl). The next day, he and his wife are served chicken soup. Mr Wickham dips a rod of magnesium oxide into the soup and holds it into the flame of an alcohol burner. The flame turns red. What does this tell him?

In this activity, the students observe spectral emission lines for various cations by performing flame tests. Using their findings, the students determine

the composition of two mixtures. This activity takes about 30 minutes.

Materials

Each group of students will require:

- Bunsen burner
- Clamp stand and clamps
- Tongs
- Magnesium oxide (MgO) rod
- Spot plate
- Hand-held spectrometer
- Safety glasses
- 5 ml 0.1 M hydrochloric acid in a small porcelain bowl
- In the spot plate, a spatula tip each of:
 - Sodium chloride (NaCl)
 - Calcium carbonate (CaCO₃)
 - Lithium chloride (LiCl)
 - Potassium chloride (KCl)
 - Mixture 1 (NaCl and CaCO₃)
 - Mixture 2 (LiCl and KCl)

Mixture 1 should be finely ground in a mortar so that the students cannot recognise the ingredients. Prepare this immediately before the lesson because calcium carbonate is hygroscopic.

Image courtesy of Alan Cleaver; image source: Flickr



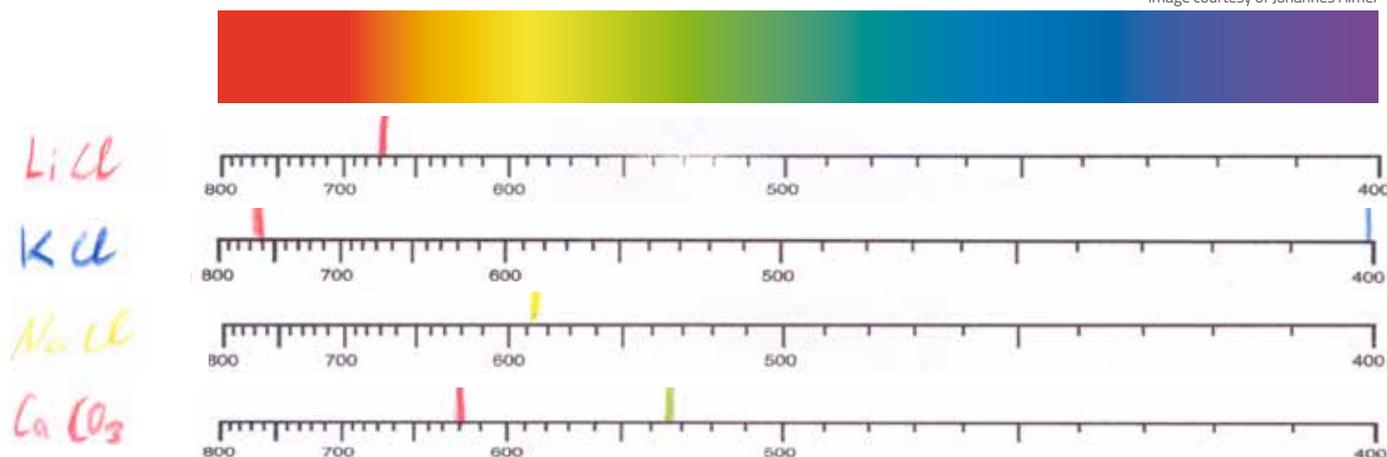


Figure 6: Students record the wavelength and colour of each cation (Li^+ , Na^+ , K^+ and Ca^{2+}).

Procedure

Ask your students to:

1. Hold the magnesium oxide rod in the flame of the Bunsen burner until the colour of the flame remains unchanged.
2. Dip the rod into hydrochloric acid, then into one of the named metal salts (LiCl , NaCl , KCl or CaCO_3) on the spot plate. Hold the rod in the hottest part of the flame. Note the colour of the resulting flame and observe it with the spectrometer.
3. Once the flame colour has returned to normal, repeat the flame test with another salt until all four have been tested.
4. Record the resulting colours and spectral emission lines for each cation (Li^+ , Na^+ , K^+ and Ca^{2+} ; see figure 6).
5. Repeat the flame test with mixtures 1 and 2. Compare the results with the previous data and identify the cations present in the two mixtures.
6. Consider the story that introduced this activity. What was Mr Wickham trying to test? How likely do you think he is to get reliable results from his experiment, without using a spectrometer?

Activity 3: LEDs and voltages

This activity further investigates the topic of spectral colours. Students determine the energy required to light

up different coloured LEDs using the following equation:

$$\text{energy (E)} = \text{voltage (V)} \times \text{charge (Q)}$$

LEDs are produced by the junction of two 'doped' semiconductor materials, one of which has an excess of electrons and the other a lack of electrons (André & André, 2014). When an electrical current is injected through the junction, the recombination of electrons releases energy in the form of photons. Each colour of LED has a different threshold voltage at which photons are released, which determine the colour of the light emitted by the LED; changing the chemical composition of the semiconductor materials thus changes the colour. Optionally, students also compare spectral emissions lines for various other light sources. They will need about 30 minutes to complete the activity.

Materials

- LEDs of different colours and (optionally) other light sources
- Power supply with current limiter (rheostat)
- Multimeter (for voltage measurement)
- Spectrometer

Procedure

Ask your students to:

1. Set up the circuit by connecting the multimeter in parallel to the LED to measure the voltage across it. The applied voltage can be changed using the rheostat.

2. For each LED, increase the voltage of the power supply in small steps (e.g. 0.05 V) until sufficient voltage is applied to light up the LED. Students should not apply more than 3.5 V to the circuit.
3. Use the multimeter to measure the voltage applied directly to the LED. Note the minimum voltage required to light up the LED.
4. Use the spectrometer to observe and record the spectral emission lines for each LED (figure 7). Optionally, compare this with other light sources (e.g. ceiling light, Bunsen burner).

Safety note: We use a current-limited power supply with a maximum current of 100 mA to avoid overvoltage and damage to the LEDs. Alternatively, arrange the LEDs in a parallel circuit with a 100 Ω protective resistor for a red or orange LED.

Poster presentation

When your students present their posters to the class, encourage them to consider the implications of the three activities and the links between them, highlighting the power of spectral analysis. Acoustic spectra can be used as 'fingerprints' (e.g. for wine glasses) in much the same way as light spectra can be used to identify atoms. In particular:

- Would they have been able to identify the murderer if he had drunk from his glass after clinking glasses with Sir Ernest?

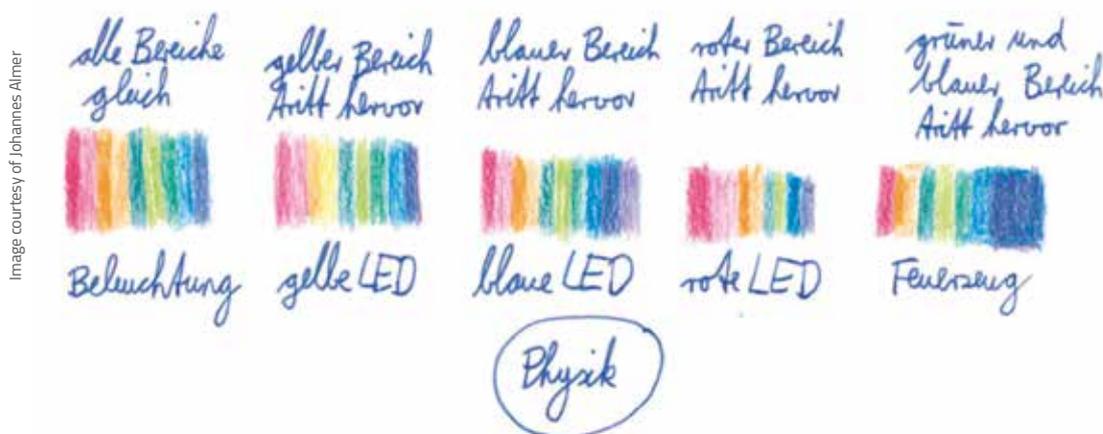


Figure 7: Students draw the spectral emission lines for each light source they observe through the spectrometer. From left to right: ceiling light, yellow LED, blue LED, red LED, cigarette lighter

- Why would changing the volume of water in a glass change its pitch?
- Using two different spectra, explain how you can identify a glass with a higher pitch.
- What was Mr Wickham testing with the chicken at Netherfield Hall, and why?
- How are emission lines related to the energy level of the atoms involved?
- What is the relationship between voltage and LED colour?

Acknowledgement

This article is based on a project that was presented at the German Science on Stage festival in 2016. Science on Stage^{ws} is the network for European science, technology, engineering and mathematics (STEM) teachers, which was initially launched in 1999 by EIROforum, the publisher of *Science in School*. The non-profit association Science on Stage brings together science teachers from across Europe to exchange teaching ideas and best practice with enthusiastic colleagues from 25 countries.



Reference

André MRASF, André PSB (2014) Classroom fundamentals: measuring the Planck constant. *Science in School* **28**: 28–33. www.scienceinschool.org/2014/issue28/planck



Images courtesy of Nicola Graf

Resources

To learn more about how spectra were discovered and how different spectra can be used to identify the composition of stars, see:

Ribeiro C, Ahlgren O (2016) What are stars made of? *Science in School* **37**: 34–39. www.scienceinschool.org/2016/issue37/stars

For instructions on how to build your own spectrometer, see:

Westra MT (2007) A fresh look at light: build your own spectrometer. *Science in School* **4**: 30–34. www.scienceinschool.org/2007/issue4/spectrometer

Examples of real-life applications of spectral analysis, further worksheets about Fraunhofer and the ChemCam of the Mars Curiosity rover are available on the authors' website. See: www.edu-maphy.de

Web references

- w1 The Audacity software is free to download for Linux, Mac and Windows. See: www.audacityteam.org
- w2 The introductory video is available on YouTube. See: www.youtube.com/watch?v=yqzgfDr9XKQ. Audio files, worksheets and other materials are available on the *Science in School* website. See: www.scienceinschool.org/2017/issue40/murder. German versions of the materials are also available. See: www.edu-maphy.de
- w3 Suitable free frequency analysis apps include:
Android Spectral Audio (download from Google Play)
- w4 Suitable free tuner apps include:
Android DaTuner (lite) (download from Google Play)
Apple iOS Soundcorset (download from Apple App store)
Apple iOS SpectrumView (download from Apple App store)
- w5 Visit the Science on Stage website. See: www.science-on-stage.eu

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